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THE IMPACT OF CLIMATOLOGICAL VARIABILITY ON SURFACE WATER SUPPLY IN OKLAHOMA

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTER OF SCIENCE

IN METEOROLOGY

By

CHARLES CHRISTIAN OLSEN

Norman, Oklahoma

1982

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THE IMPACT OF CLIMATOLOGICAL VARIABILITY ON

SURFACE WATER SUPPLY IN OKLAHOMA

A THESIS

APPROVED FOR THE SCHOOL OF METEOROLOGY

By

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ABSTRACT

The frequency and duration of surface water deficits in two river basins in western Oklahoma and the Texas Panhandle are examined for the thirty years, 1951-1980. The studied basins were divided into a total of 10 subbasins. A hydrologic accounting system, using precipitation and temperature as inputs, was used to derive variables such as potential (PET) and actual (ET) evapotranspiration, soil moisture and runoff. These were combined with basic hydrologic variables (stream discharge and lake contents) to calculate long-term weekly mean values and 75 percent empirical ranges for surface water storage and demand. Potential deficit periods were identified and examined using percentage frequency histograms and joint frequency tables. From these it was determined that surface water deficits existed in as many as 47 percent of the thirty years studied. The potential deficit period ranged from 2 weeks to 29 weeks, averaging 17 weeks.

Case studies for two of the subbasins for a dry year, a wet year and an "average" year are presented. Background climatologies for weekly precipitation (30-year means and means for the 5 driest years), weekly stream discharge and weekly lake contents for each of the ten major river basins in Oklahoma are presented. These show the space and time variability of precipitation delivery across the state and the extent to which statewide dry periods are reflected in individual river

basins. Possible applications of surface water storage, demand and deficit climatologies that were developed are presented. An appendix with complete time-series climatologies for all variables for all sub-basins of the two major basins studied is also included.

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The frequency and duration of surface water deficits in two river basins in western Oklahoma and the Texas Panhandle are examined for the thirty years, 1951-1980. The studied basins were divided into a total of 10 subbasins. A hydrologic accounting system, using precipitation and temperature as inputs, was used to derive variables such as potential (PET) and actual (ET) evapotranspiration, soil moisture and runoff. These were combined with basic hydrologic variables (stream discharge and lake contents) to calculate long-term weekly mean values and 75 percent empirical ranges for surface water storage and demand. Potential deficit periods were identified and examined using percentage frequency histograms and joint frequency tables. From these it was determined that surface water deficits existed in as many as 47 percent of the thirty years studied. The potential deficit period ranged from 2 weeks to 29 weeks, averaging 17 weeks.

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THE IMPACT OF CLIMATOLOGICAL VARIABILITY ON SURFACE WATER SUPPLY IN OKLAHOMA

CHAPTER I

INTRODUCTION

1.1 Background on Water Problems

Mean yearly precipitation across the State of Oklahoma varies widely, from less than fourteen inches[1] in Cimarron County in the extreme western panhandle to over fifty-two inches in the southeastern corner (Figure 1). As one would expect, this range of precipitation manifests itself in different ways; of interest to this study is the effect on the availability of surface water supplies, especially in the western one-half of the state.

Much of the economy of western Oklahoma depends heavily on agriculture, which in turn depends critically on water supplies (W. S. Cooter, 1981). Surface and groundwater sources can provide varying portions of the total water required. The contribution from each source depends on the area and the year-to-year precipitation variability (see Chapter II). Western Oklahoma uses groundwater extensively. In fact,

[1] English units (inches, acres, etc.) instead of metric units were used throughout this thesis because the data were available in those units.

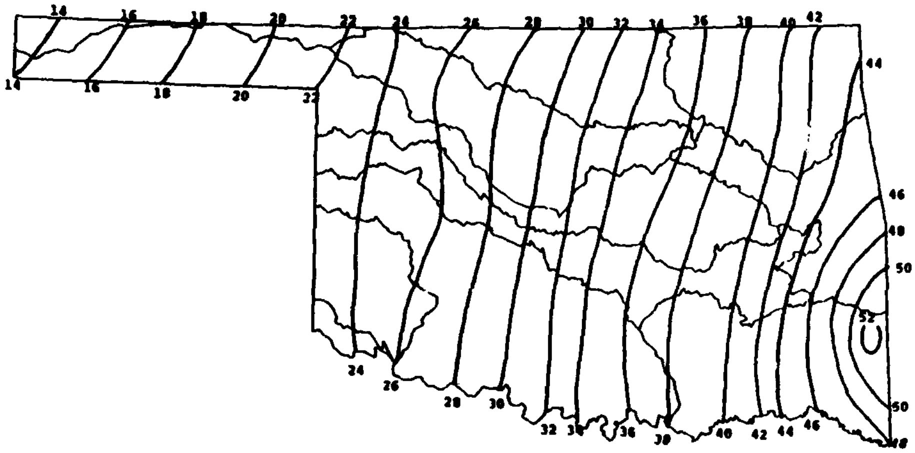

Figure 1. Mean annual precipitation for Oklahoma (in inches); base map with river basins. (Isohyets after Pflaum, 1982)

according to the Oklahoma Water Resources Board (OWRB), eighty percent of total statewide groundwater usage occurs in the western third of Oklahoma (OWRB, 1976). In many areas, however, the groundwater is a non-renewable resource. For example, the Ogallala aquifer that underlays the Oklahoma panhandle and which has largely been responsible for the boom in irrigated agriculture of the last twenty years, is basically non-rechargeable. That is to say, the slow recharge rate is very much less than the current withdrawal rate. In fact, "only 1.5 percent of the annual rainfall, or one-fourth inch, reaches the water table. Groundwater in the Ogallala is being mined" (OWRB, 1976).

Regardless of whether the subsurface waters are replenishable or not, the cost of obtaining and using that water (drilling, pumping, irrigating) is increasing with rising energy costs. For those reasons (dwindling resources, increased costs) subsurface water will probably play a decreasing role in the next twenty years. Conversely, surface

water supplies will play an increasingly important role in the economy of central and western Oklahoma.

It is paramount that existing surface water supplies be used and managed judiciously. That means, for example, that water planners and decision makers should have appropriate tools to use in making their decisions. One of these tools should be information that will help them assess current versus future water utilization strategies given a particular set of circumstances. The potential applicability of such decision aides is wide-ranging but certainly includes:

- agricultural; irrigation use/scheduling,
- municipal and industrial,
- flood control, and
- weather modification (rainfall augmentation).

1.2 Drought

Many terms are defined and used in this thesis. However, one term which is not used explicitly should be discussed briefly here. That term is drought. It is a highly situation-specific concept. That is, its definition changes from location to location, from time to time in the same location and from one area of interest to another (e.g., agriculture, hydrology, municipal supply). Curry (1973) gives examples of agricultural drought, hydrologic drought and meteorologic drought. Rosenberg (ed., 1979) defines agricultural drought as a "climatic excursion involving a shortage of precipitation sufficient to adversely affect crop production and range productivity." The Glossary of Meteorology (Huschke, ed., 1959) gives the following general definition of drought:

> A period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area. Drought severity depends upon the degree of moisture deficiency, the duration, and to a lesser extent, the size of the affected area.

Cox (in Rosenberg, ed., 1979) defines climatological drought as follows:

> Rainfall is below average. There is simply not enough rain. Yields are reduced although rarely are crops totally lost.... Occurrence of the drought is evident in conventional weekly, monthly and annual records.

Cox further defines hydrologic drought as:

> ...meteorological drought prolonged. Lakes and reservoirs shrink in size. Water tables drop and springs dry up.... Information on the drought becomes more readily available because of the impacts on towns, cities, irrigation districts, etc.

Drought can also be defined in a sociological context, as its ultimate effect is on people (e.g., Jensen, 1978; Bollman and Merritt, 1978).

Drought indices have also been developed. Palmer (1965) (Palmer Drought Index) treated drought severity as a function of accumulated differences between actual and required precipitation. Palmer (1968) also used a crop moisture index (CMI) that defined agricultural drought severity in terms of evapotranspiration deficit. Jensen (1978) developed a drought severity index that specifically considers municipal, industrial and agricultural demand.

The foregoing is only a brief selection of drought definitions. It is because of this plethora that the word drought has been avoided in deference to other terms which are more narrowly defined in the context of the study. Nonetheless, just as it is the scarcity of water available for use by people who need it which has been the motivation behind these many studies; it is the relationship between the supply

and demand of "surface" waters, particularly when these two factors approach each other in magnitude, that forms the focal point of this report. Our surface water budget will be concerned with storage and changes in streams, lakes and soil moisture in Oklahoma with particular attention paid to "drought" conditions.

1.3 Objectives of Research

The research reported in this thesis was undertaken with three principal objectives.

a. The first objective was to meld the salient hydrologic and meteorologic variables to derive new variables that would be useful in examining surface water supplies. The follow-on to this objective was to produce climatologies of these variables.

b. The second objective was to develop climatologies of water availability (i.e., storage) and demand and then to examine these for possible critical periods; for example, when a deficit (demand greater than storage) might be expected to occur.

c. The third objective of the research was to determine that intelligence could be gleaned from the climatologies above, and, to present it in a form that could be of assistance to decision makers.

CHAPTER II

OVERVIEW OF STATEWIDE WATER RESOURCES

2.1 Major Basins

There are two major river basins in Oklahoma, the Arkansas and the Red. The smaller basins that comprise these two major basins, however, are defined somewhat differently, depending on the agency involved. For example, the U.S. Army Corps of Engineers (1979) identifies fourteen river basins in Oklahoma. On the other hand, the Oklahoma Water Resources Board uses ten basins (Springer, 1982, personal communication).[2] The statewide river basins used in this study follow those used by the OWRB, and are illustrated in Figure 2.

2.2 Hydro-Meteorologic Setting

As background for this thesis, mean precipitation data are presented for each river basin while mean stream discharge and lake contents are shown for selected hydrologic sites within each basin. Figure 1 illustrated the west to east rainfall gradient across the state. The average annual precipitation for Oklahoma is 33.03 inches. However, as Figure 3 shows, during a recent thirty year period (1951-1980) the average statewide precipitation varied from less than 21 inches to over

[2]Harold L. Springer, Professional Engineer, Chief, Engineering Division, Oklahoma Water Resources Board, Oklahoma City, Oklahoma.

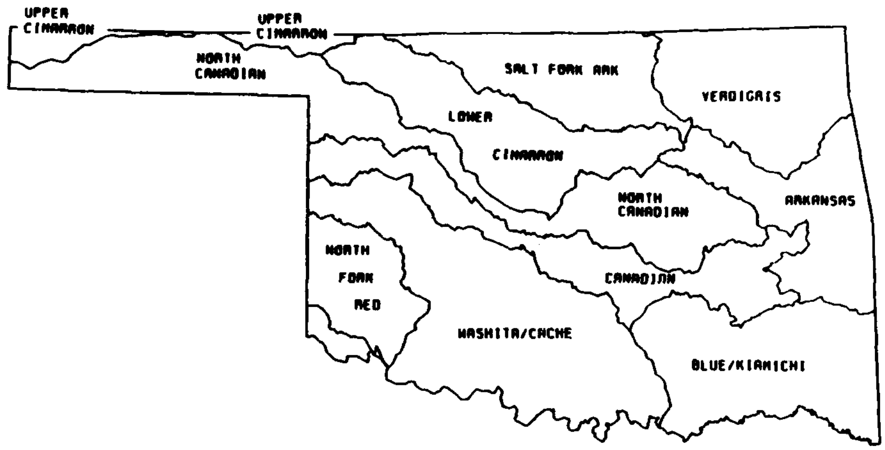

Figure 2. River basins in Oklahoma. (After Oklahoma Water Resources Board, 1982)

48 inches, a variation of over a third each way. Figure 3 also clearly shows the very dry early 1950s and the very wet late 1950s. Average annual precipitation is broken down by river basin for the 30 years and the 5 driest years in Figures 4 and 5. Figure 6 is the average weekly precipitation for Oklahoma; both the 30-year means (1951-1980) and the mean for the five driest years within those 30 years are plotted. The five driest years are 1952, 1954, 1956, 1963 and 1966. General statewide precipitation patterns are evident. There are two precipitation peaks, the largest in late spring and a secondary peak in late summer. The apparent culprit in the five driest years was not the spring rain, although it was less than average, but rather the widespread lack of fall rain (only a third of normal).

Figures 7 through 16 provide similar information for each of the ten river basins. Each shows the average weekly basin precipitation

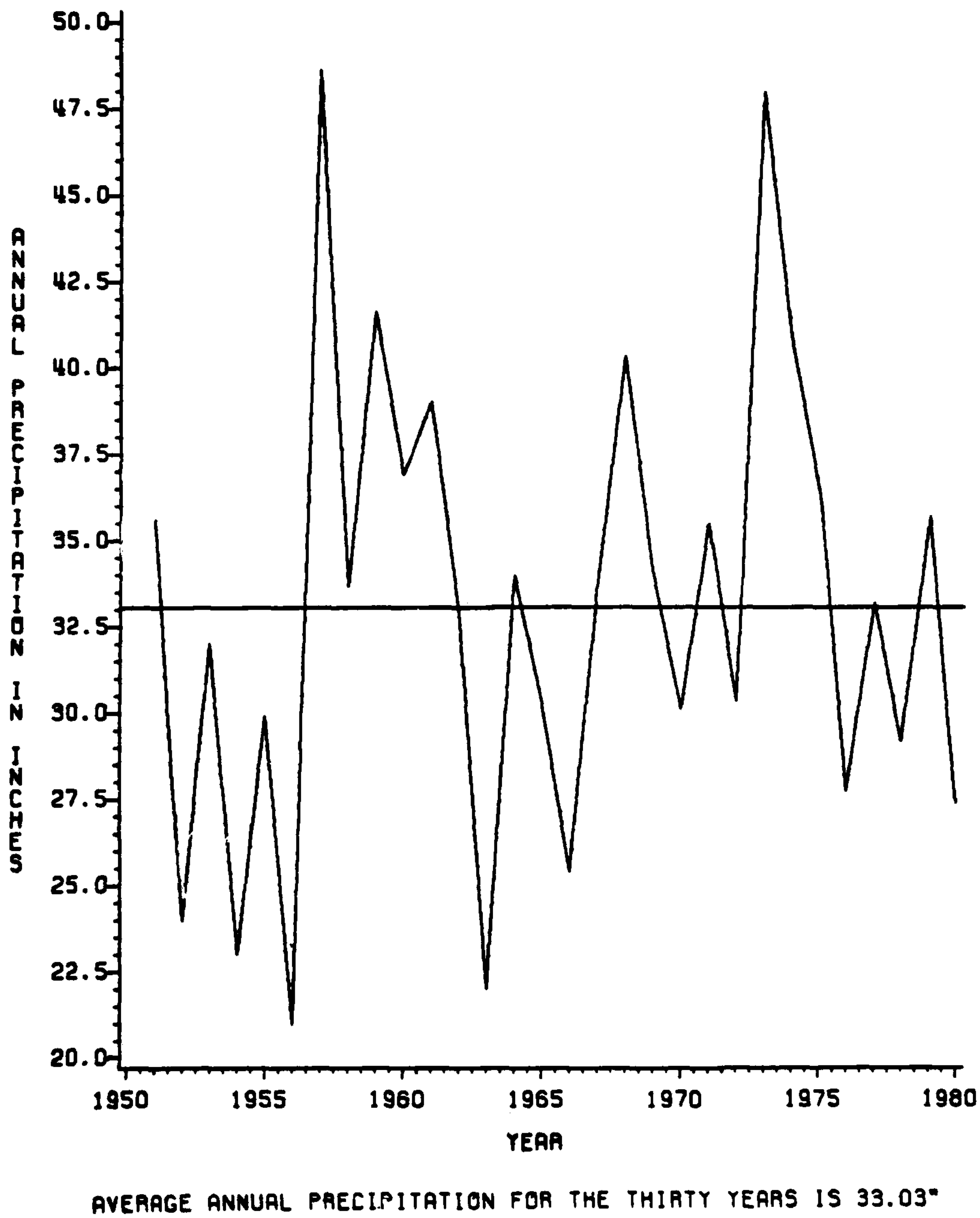

Figure 3. Average annual precipitation for Oklahoma for the thirty year period (1951-1980).

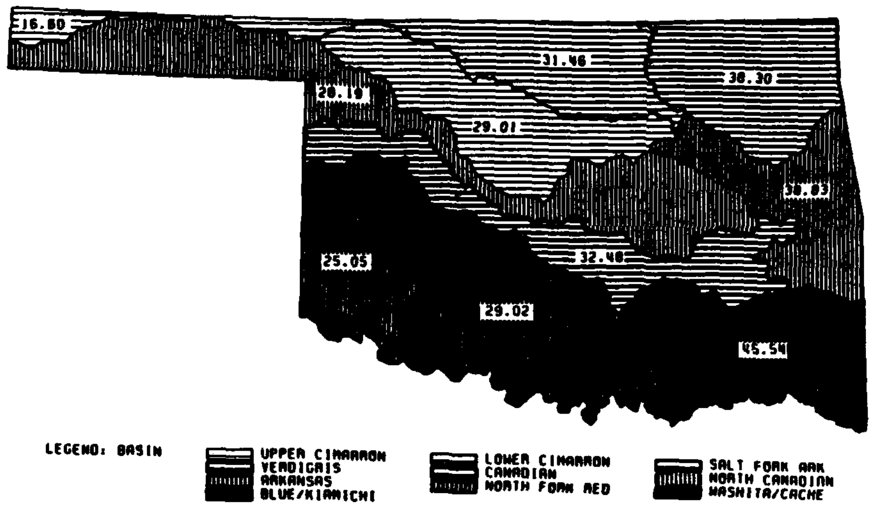

Figure 4. Mean annual precipitation by river basin (in inches) for the thirty year period 1951-1980.

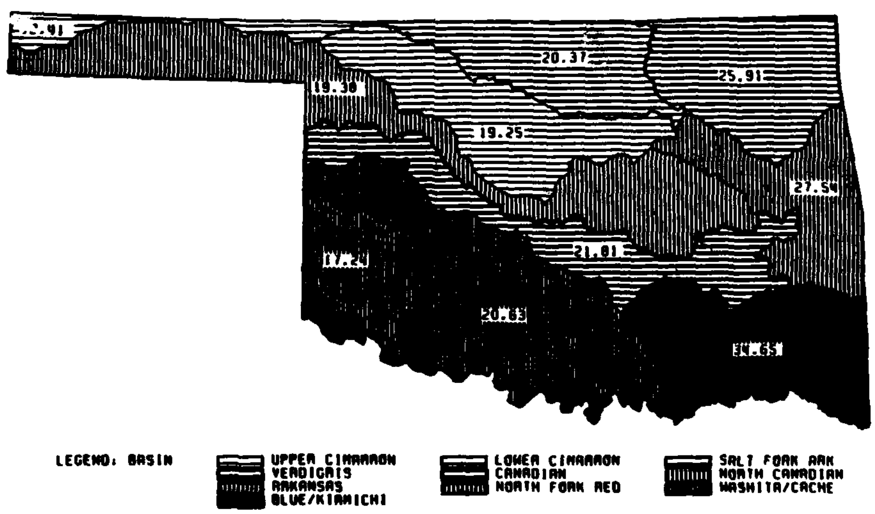

Figure 5. Mean annual precipitation by river basin (in inches) for the five driest years between 1950 and 1980; years are 1952, 1954, 1956, 1963, 1966.

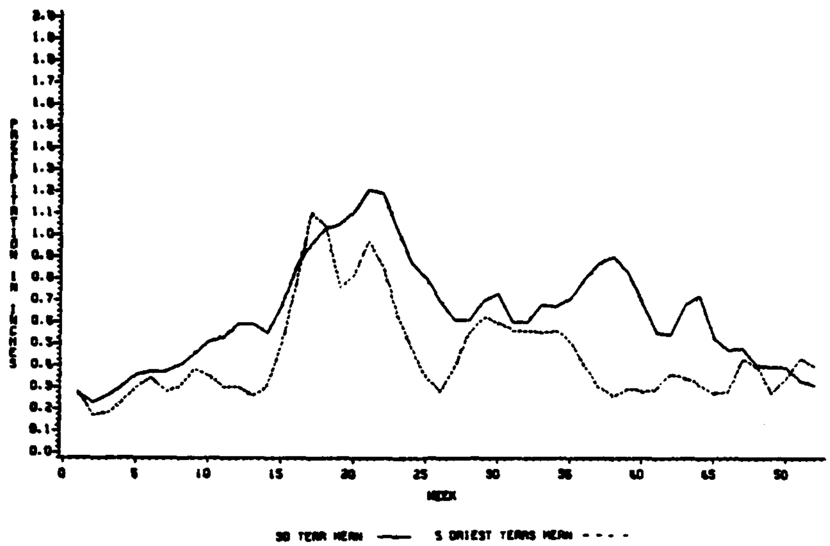

Figure 6. Mean weekly precipitation for Oklahoma; 30-year means, five driest years means.

for the 30 years and the driest five years. Note that the five driest years used are the five driest for the state, but not necessarily for every basin. The figures also show 30-year averages for total weekly stream discharge for a selected station in the basin and 30-year average weekly lake contents for a lake in the basin, if available.[3] The precipitation data are filtered, using a 3-point Hanning filter (weights: .25, .5, .25); the hydrologic data in this chapter are not filtered. Although the stream and lake data are overlayed, no exact cause and effect relationship should be assumed because the stream gauging station is not necessarily immediately above or below the lake.

Since the data in this chapter are offered primarily as background to the detailed study that follows, a rigorous discussion of Figures

[3]Since weekly data were used throughout this thesis, units which are listed as "acre feet" have the implied time unit of weeks, i.e., acre feet per week.

7-16 is not presented. However, several general and important points must be highlighted. Referring to Figure 2 we note that most of the river basins are elongated generally west-east. This is the direction of maximum rainfall gradient across Oklahoma (Figure 1). Consequently, the average rainfall in part of the basin may vary greatly from that in another part. For example, the North Canadian River basin extends more than three-quarters of the way across the state; the average rainfall in the basin ranges from less than fourteen inches to greater than forty inches. In the context of this study, however, the averaging effect of using basin rainfall is appropriate because we are less concerned with rainfall at a point than with rainfall across the basin, as manifested in the total surface water available.

The patterns of mean basin precipitation are generally similar; there is a peak in late spring and a second, smaller peak in the late summer. Only in the extreme northwest (Upper Cimarron basin, Figure 7a) is the summer peak as large as the one in spring. Basins in the southeast that are less elongated (e.g., Verdigris, Blue/Kiamichi, Figures 10a, 16a) show broader precipitation peaks. That is, periods of maximum precipitation last longer, but the double-peaked (spring, summer) general pattern mentioned above is still seen.

The patterns for the five driest years also generally follow the statewide characteristics, with less precipitation in the spring, but very much less than average in the late summer. There are several exceptions to this: the Upper Cimarron (Figure 7a) had heavier than average late summer precipitation; the North Fork of the Red (Figure 14a) had average spring precipitation; and, the Blue/Kiamichi (Figure 16a)

had a greater than average early spring peak; however, the total spring rainfall was less than the mean. Actually, considering the often capricious nature of drought (e.g., limited to one area, or missing one area while affecting all around it) (Curry, 1973; Rosenberg, ed., 1979), the extent to which the five driest years (statewide) are reflected in all river basins is interesting.

The selected stream discharge data show similar patterns, with a large discharge peak in the late spring and a smaller peak in the late summer. Both of these are related to similar precipitation maxima. The Cimarron River near Kenton, Oklahoma (Upper Cimarron basin, Figure 7b) shows wide discharge fluctuations from spring to fall. However, the discharges are quite small (maximum 800 acre feet per week). Also the Verdigris River near Oolagah, Oklahoma (Verdigris River basin, Figure 10b) has a dramatic discharge peak in early fall. A partial explanation for this may be the apparent release from Oolagah Lake the previous week.

Across the state, the yearly change in lake contents is also similar. Most lakes follow the general pattern of increasing contents through the spring, a fairly rapid decrease through the summer and another, smaller increase in the fall (e.g., Figure 9b). This pattern generally follows those for precipitation and stream discharge. Canton Lake (Figure 12b) and Altus Lake (Figure 14b) show only a spring peak with very little or no fall recovery. This is probably due to their location, the farthest west of the lakes compared, and the lighter rainfall in their upstream basins.

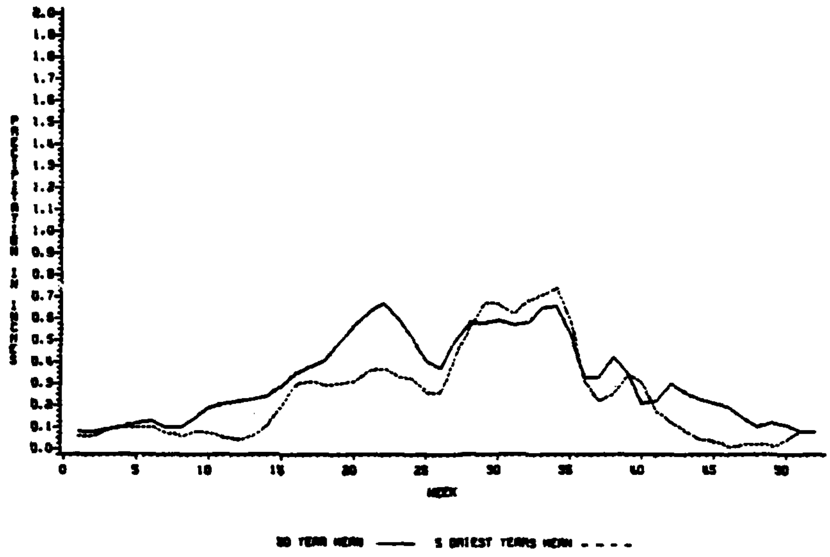

Figure 7a. Mean weekly basin precipitation for the Upper Cimarron River; 30-year means, 5 driest years means.

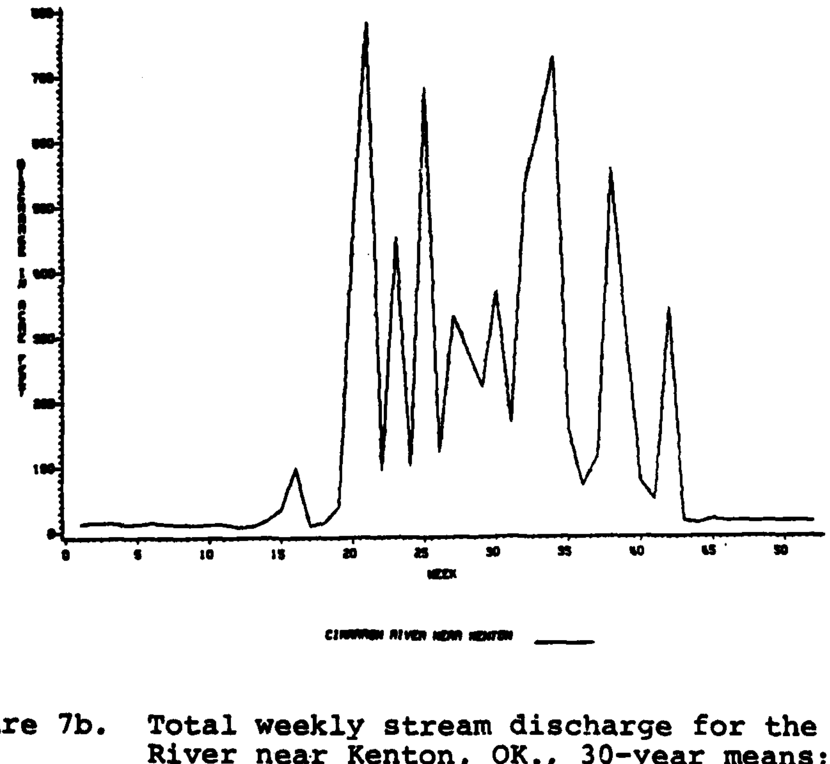

Figure 7b. Total weekly stream discharge for the Cimarron River near Kenton, OK., 30-year means; discharge in acre feet per week.

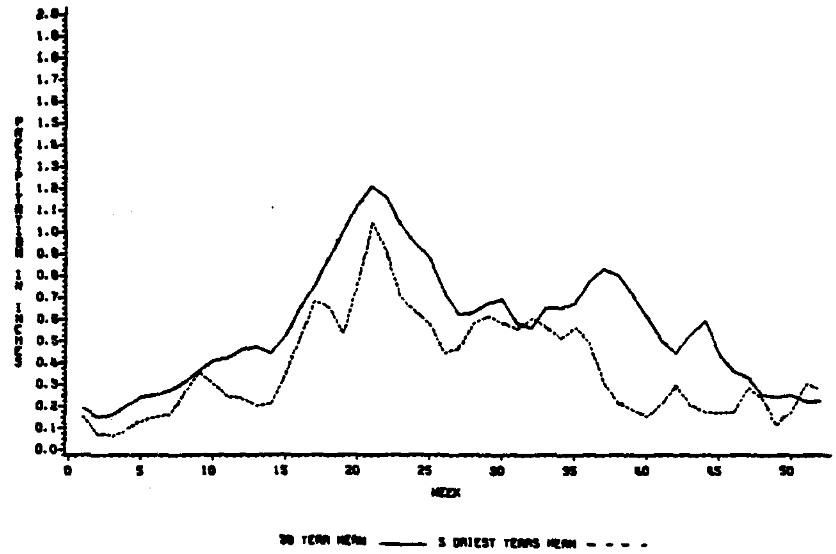

Figure 8a. Mean weekly basin precipitation for the Lower Cimarron River; 30-year means, 5 driest years means.

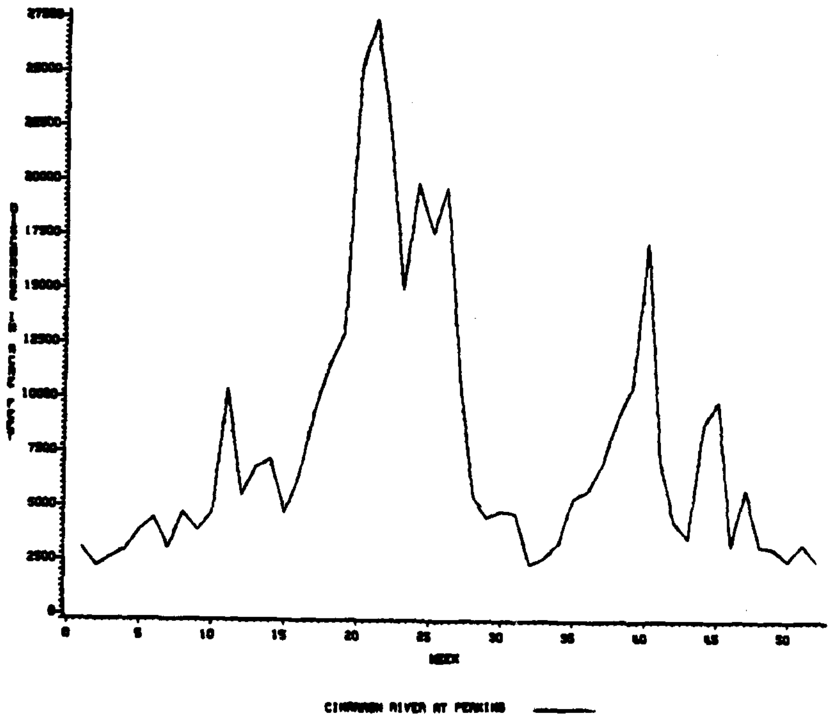

Figure 8b. Total weekly stream discharge for the Cimarron River at Perkins, OK., 30-year means; discharge in acre feet per week.

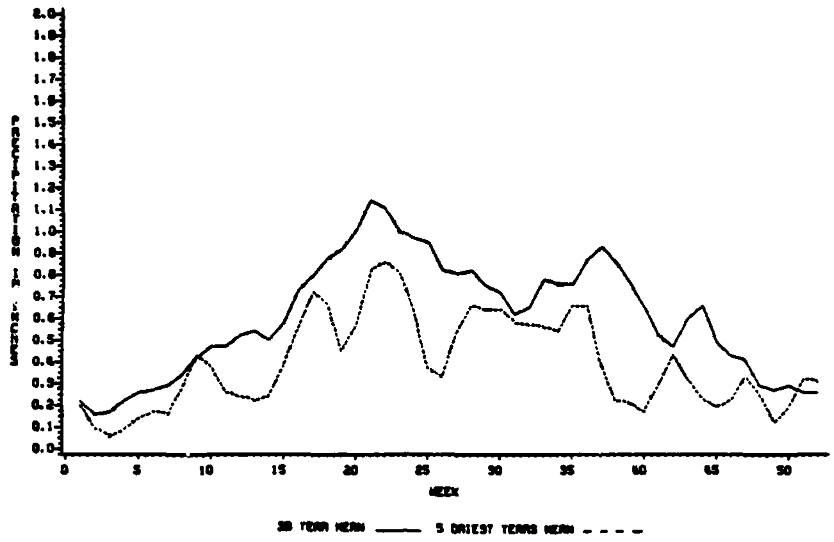

Figure 9a. Mean weekly basin precipitation for the Salt Fork of the Arkansas River; 30-year means, 5 driest years means.

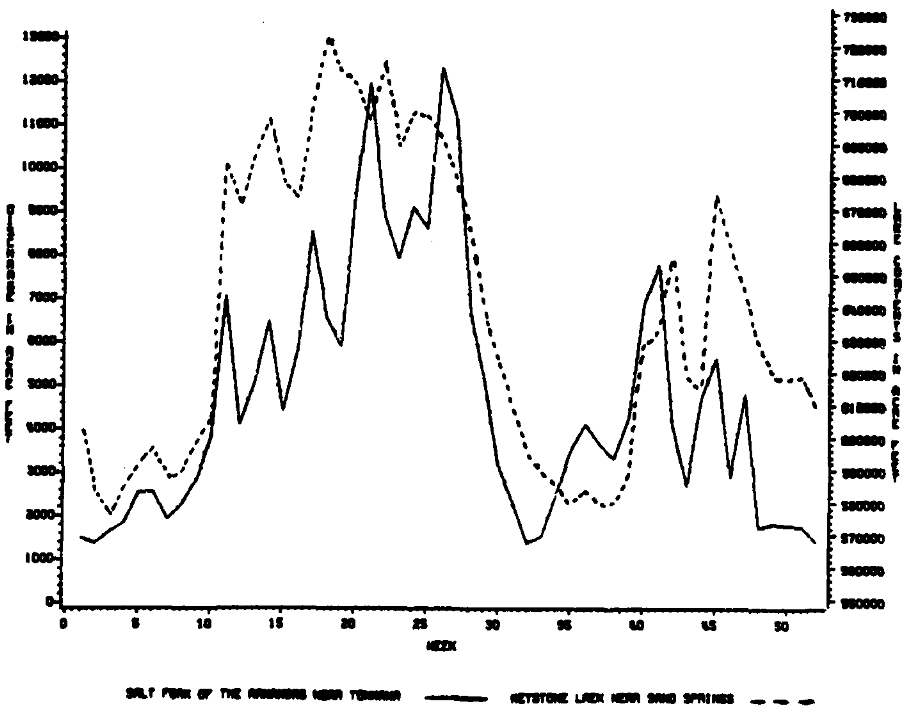

Figure 9b. Total weekly stream discharge for the Salt Fork of the Arkansas River near Tonkawa, OK, and mean weekly lake contents for Keystone Lake near Sand Springs, OK, 30-year means; discharge in acre feet per week, lake contents in average acre feet per week.

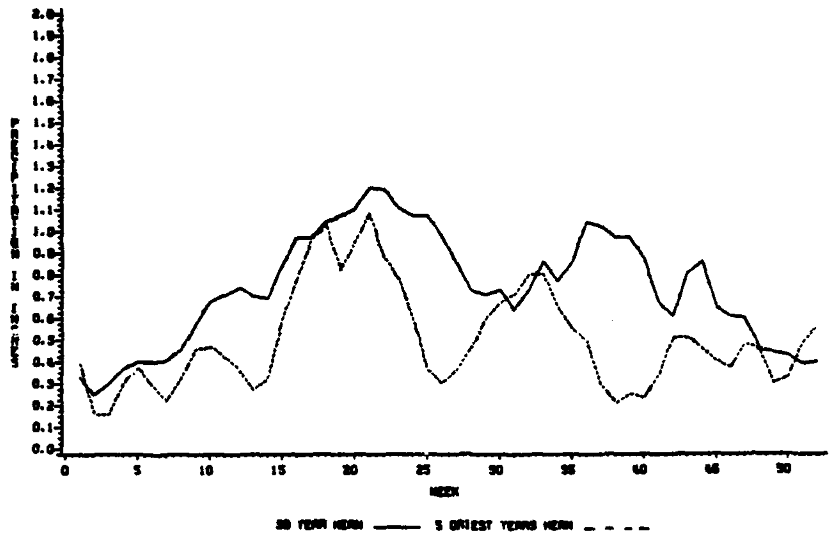

Figure 10a. Mean weekly basin precipitation for the Verdigris River; 30-year means, 5 driest years means.

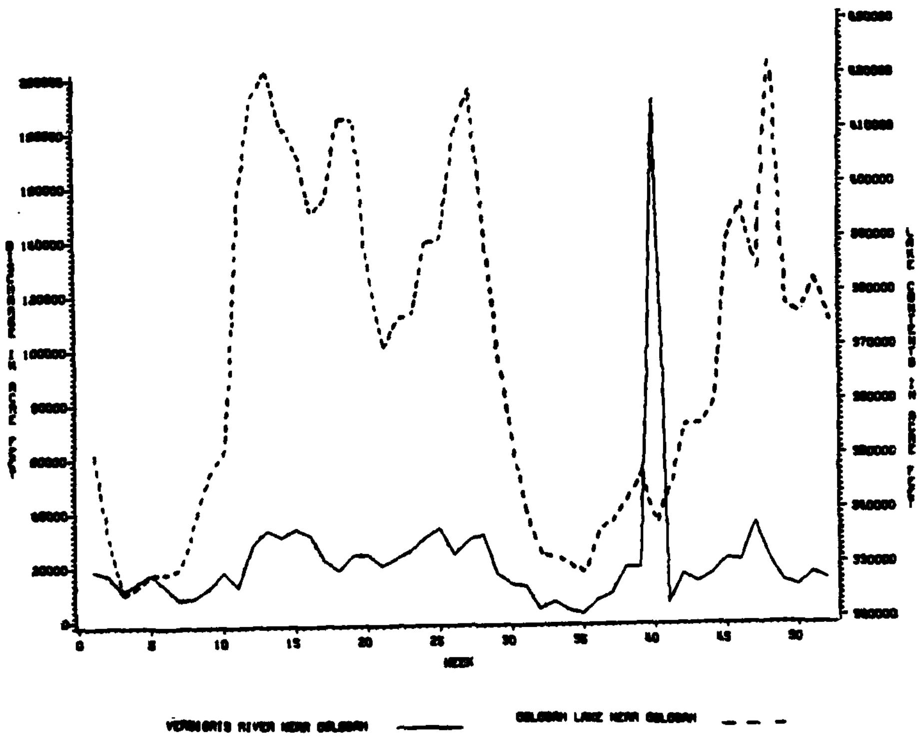

Figure 10b. Total weekly stream discharge for the Verdigris River near Oolagah, OK, and mean weekly lake contents for Oolagah Lake near Oolagah, OK, 30-year means; discharge in acre feet per week.

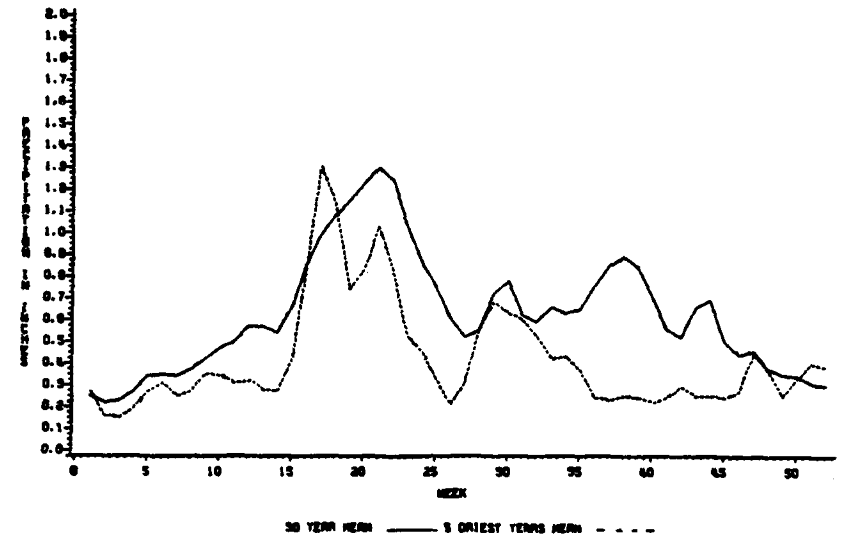

Figure 11a. Mean weekly basin precipitation for the Canadian River; 30-year means, 5 driest years means.

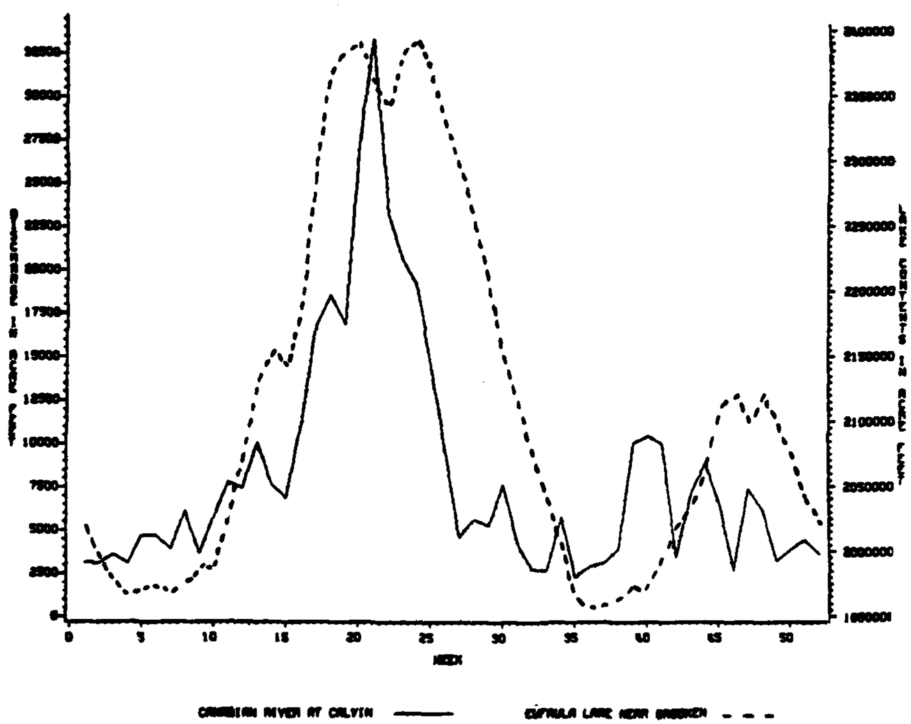

Figure 11b. Total weekly stream discharge for the Canadian River at Calvin, OK, and mean weekly lake contents for Eufaula Lake near Brooken, OK, 30-year means; discharge in acre feet per week, contents in average acre feet per week.

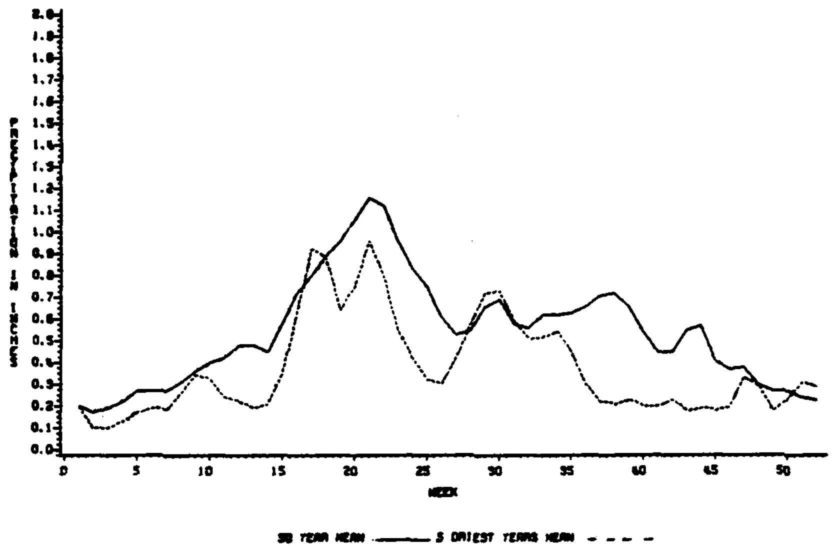

Figure 12a. Mean weekly basin precipitation for the North Canadian River; 30-year means, 5 driest years means.

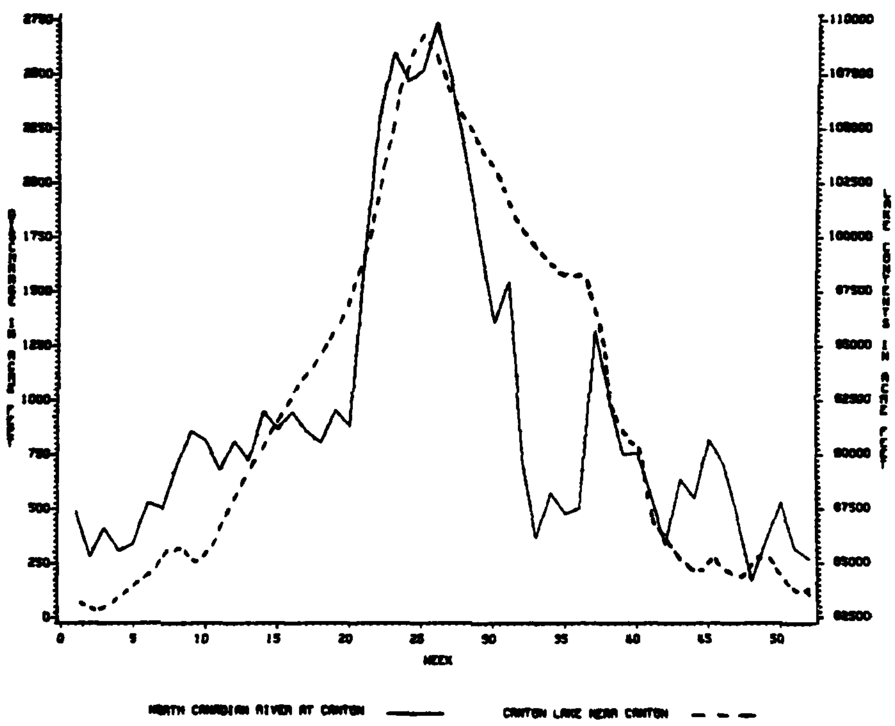

Figure 12b. Total weekly stream discharge for the North Canadian River at Canton, OK, and mean weekly lake contents for Canton Lake near Canton, OK, 30-year means (river), 15-year means (lake); discharge in acre feet per week, contents in average acre feet per week.

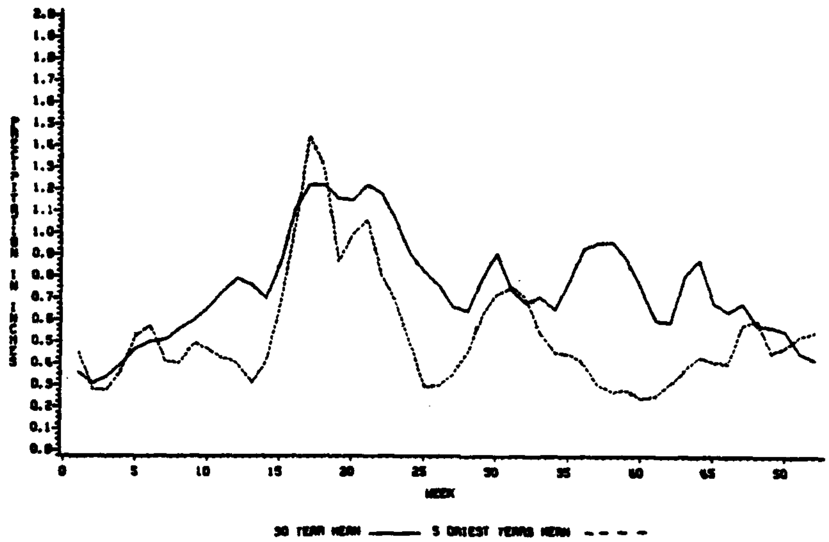

Figure 13a. Mean weekly basin precipitation for the Arkansas River; 30-year means, 5 driest years means.

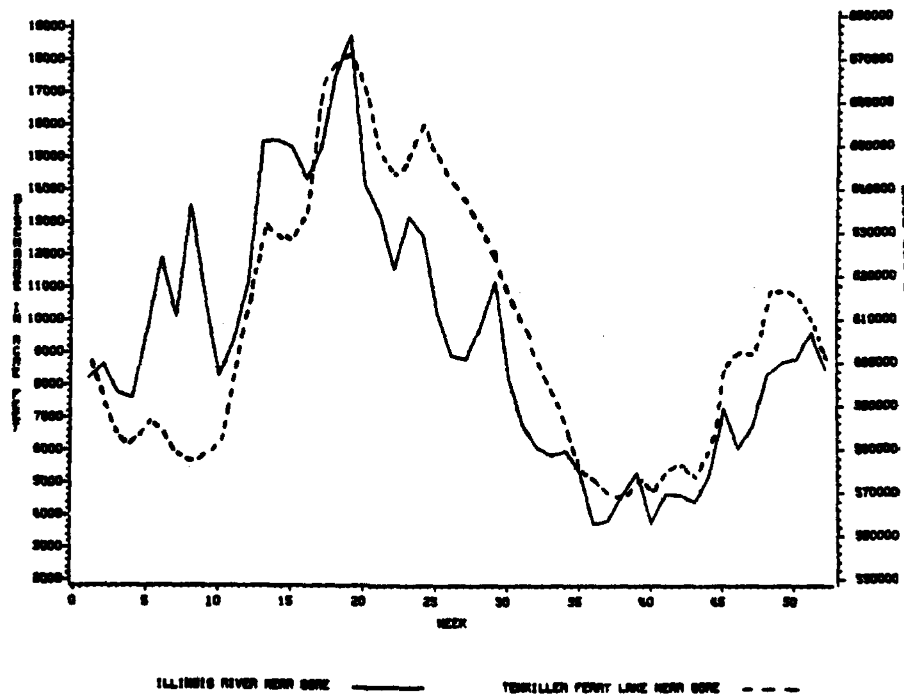

Figure 13b. Total weekly stream discharge for the Illinois River near Gore, OK, and mean weekly lake contents for Tenkiller Ferry Lake near Gore, OK, 30-year means; discharge in acre feet per week, contents in average acre feet per week.

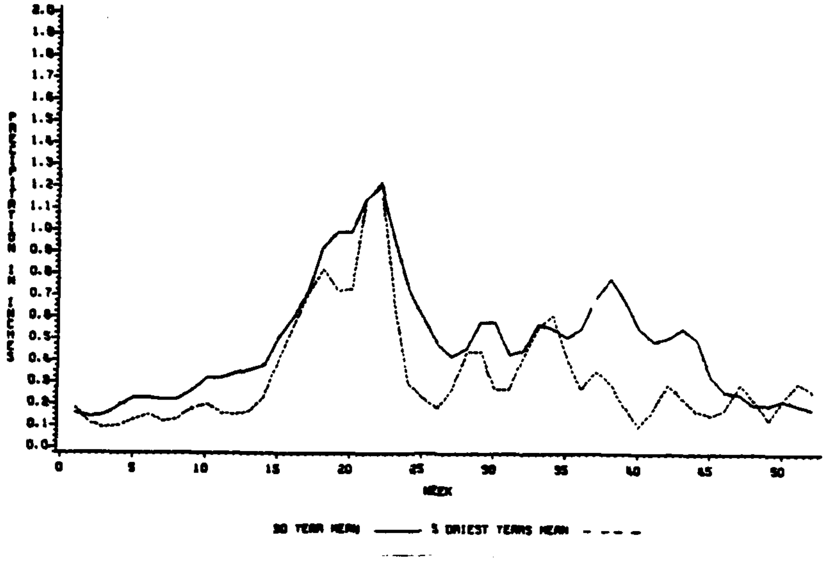

Figure 14a. Mean weekly basin precipitation for the North Fork of the Red River; 30-year means, 5 driest years means.

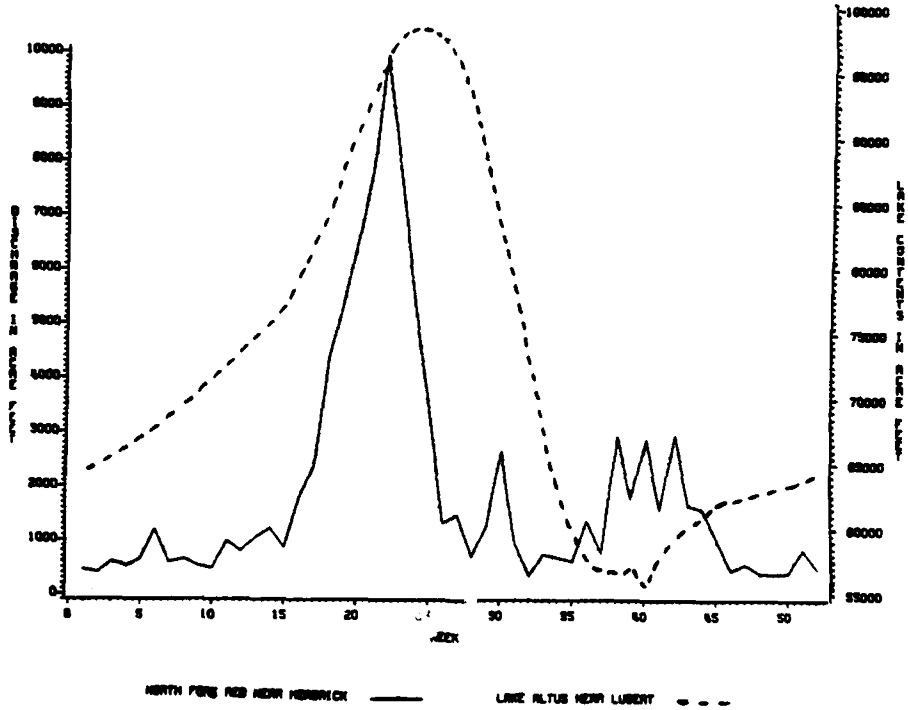

Figure 14b. Total weekly stream discharge for the North Fork of the Red River near Headrick, OK, and mean weekly lake contents for Altus Lake near Lugert, OK, 30-year means (river), 15-year means (lake); discharge in acre feet per week, contents in average acre feet per week.

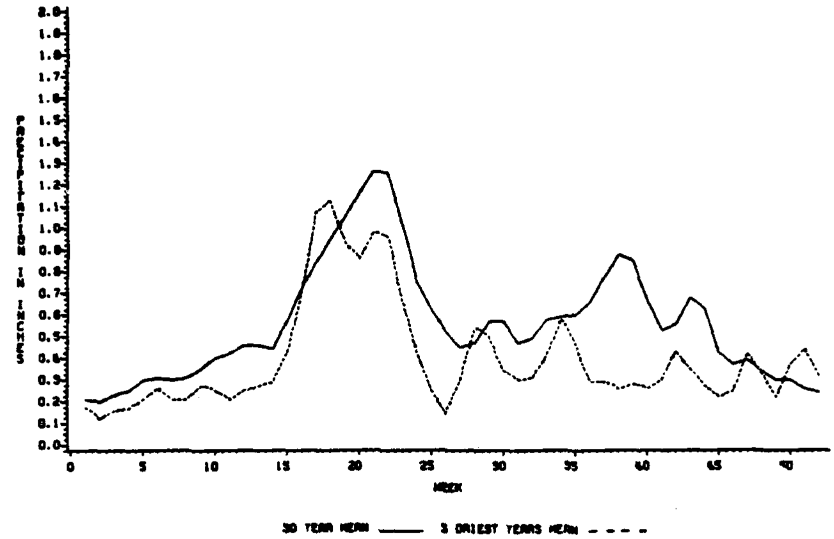

Figure 15a. Mean weekly basin precipitation for the Cache/ Washita Rivers; 30-year means, 5 driest years means.

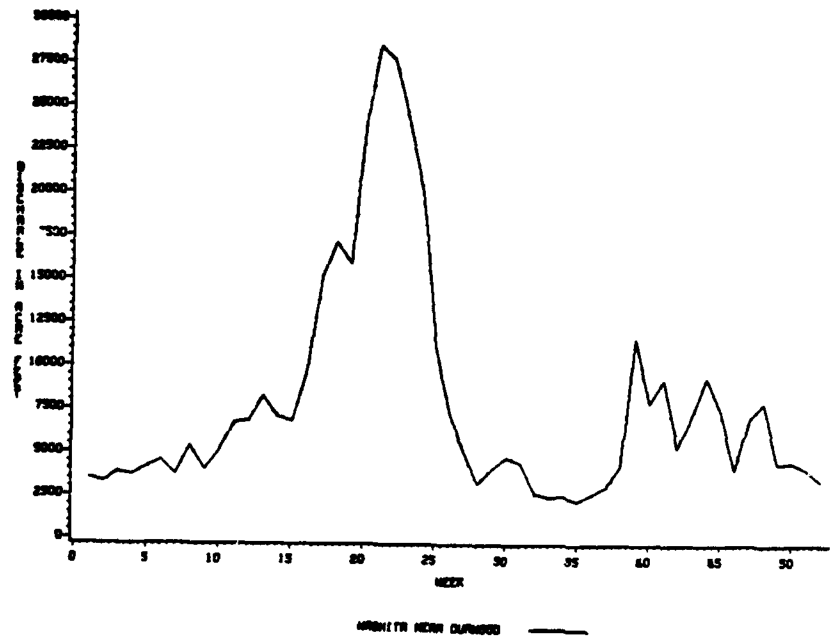

Figure 15b. Total weekly stream discharge for the Washita River near Durwood, OK, 30-year means; discharge in acre feet per week.

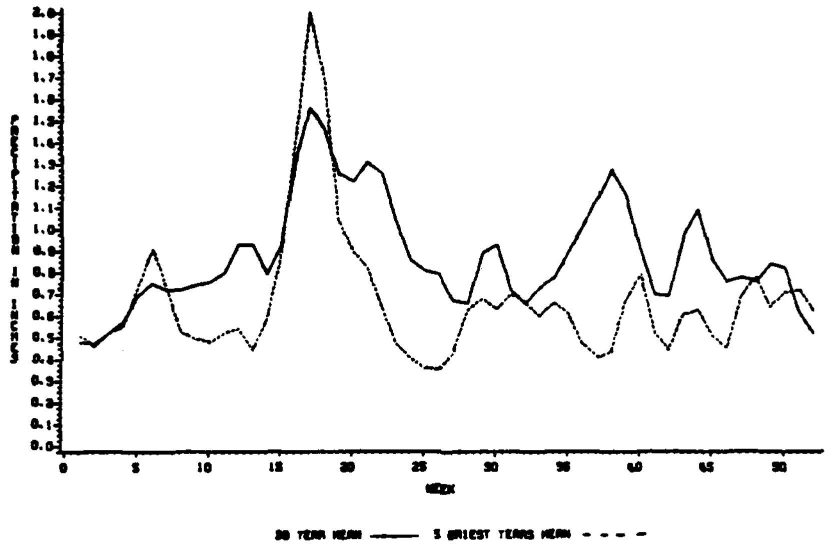

Figure 16a. Mean weekly basin precipitation for the Blue/ Kiamichi Rivers; 30-year means, 5 driest years means.

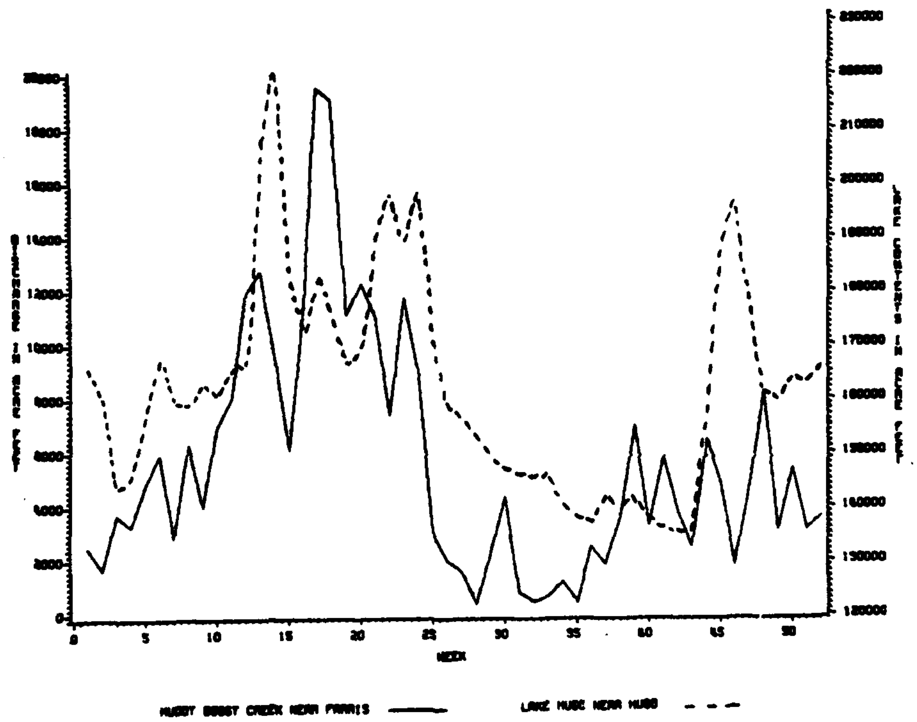

Figure 16b. Total weekly stream discharge for the Muddy Boggy Creek near Ferris, OK, and mean weekly lake contents for Lake Hugo near Hugo, OK, 30-years means; discharge in acre feet per week, contents in average acre feet per week.

CHAPTER III

IDEALIZED HYDROLOGIC ANALYSIS

A purely hydrologic study of water availability in a river basin would probably begin with the determination of base flow in the stream, using recession analysis (Hanson, 1981, personal communication).[4] The base stream flow is that portion of stream discharge not attributable to rainfall and associated runoff. Recession analysis involves the falling limb, or recession, portion of a stream hydrograph. A typical hydrograph that might result from a rainfall event has a rising limb, a crest segment, and a falling limb or recession (Figure 17). The inflection point on the recession limb is assumed to be the point at which surface runoff to the stream channel ceases (Linsley et al., 1975). Therefore, analysis of this portion of the hydrograph over a period of time and number of storm events should provide information on the base flow characteristics of the stream.

Ideally, for study, the stream would not have periods of no-flow (i.e., be dry) and would be undammed, either by reservoirs or smaller catchments. The first criterion is difficult, but not impossible, to satisfy in the western half of Oklahoma; most major rivers have at least

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[4] Ronald L. Hanson, Assistant District Chief, Water Resources Division, U.S. Geological Survey, Oklahoma City, Oklahoma.

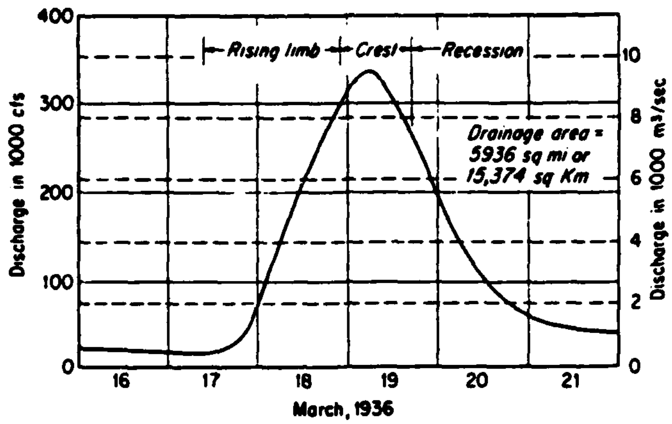

Figure 17. A typical stream hydrograph (Potomac River at Shepherdstown, WV). (From Linsley et al., 1975)

some flow year-round. The second requirement (undammed), however, is virtually impossible to satisfy except for any but the smallest streams. Major reservoirs are gauged, but the thousands of smaller catchments, stock ponds, diversions and the like are not. Sophisticated models exist that attempt to quantify the water held by these catchments (Knisel and Nicks, 1980; Nicks, 1982, personal communication).[5] However, their incorporation is beyond the scope of this study.

Due to the above difficulties a purely hydrologic investigation was not undertaken. Rather, certain simplifying assumptions, and the consequent inaccuracies, were introduced in order to approach the real-world situation in western Oklahoma, where periods of no-flow occur and where numerous dams are a fact of life. In fact, this study in agro-

[5] Arlin Nicks, Research Leader and Agricultural Engineer, Water Quality and Watershed Research Laboratory, U.S. Department of Agriculture, Durant, OK.

hydro-climatology has required approximations to be introduced from each discipline in order to produce a workable compromise.

3.1 Simplifying Assumptions for Basin Selection

Given the difficulties in applying a purely hydrologic approach to western Oklahoma, as discussed in the previous section, a compromise was used. A river subbasin was defined as the portion of a river basin between two consecutive stream gauges. Thus, measurements of inflow and outflow for that subbasin were obtainable. If a reservoir existed it was bracketed by stream gauges, so that discharge from the reservoir could be calculated, at least approximately. Further, by using a thirty-year period of data a stable average stream flow for a period could be determined, although the true hydrologic base flow could not be. In light of the objectives of this investigation, namely to develop various climatologies which would permit intelligence to be extracted from the data, it was felt the simplifications above were within the resolution of the study.

3.2 Basin Selection Criteria

Three basic criteria were considered in selecting the two basins for study. Foremost, the basins should be in the western one-half of the state, since that is where the most serious water problems exist. Secondly, the basins should contain at least one controlled reservoir. The reservoir serves as an ideal decision, or control point, where decision assistance information from this study could be implemented. Thirdly, the primary water uses in the two basins should be different, e.g., agricultural or municipal.

3.3 Basin Selection and Description

The two basins selected for study were a portion of the North Canadian River, from Beaver, Oklahoma to Harrah, Oklahoma, and a portion of the North Fork of the Red River, from its headwaters in the Texas panhandle to Headrick, Oklahoma. Hereinafter the basins chosen will be referred to as the North Canadian and the North Fork without the modification "a portion of." If the entire basin is referenced this will be specifically stated.

3.3.1 North Canadian River

The North Canadian River has its source in Union County, New Mexico and enters Oklahoma in Cimarron County. The portion of the basin used in this study (Figure 18) begins at Beaver, Oklahoma, in Beaver County. From there the river flows southeastward through Oklahoma City and Harrah (both in Oklahoma County), where the basin for this study terminates (OWRB, 1976).

The water in the North Canadian is used primarily for municipal and industrial purposes, largely by Oklahoma City. Canton Dam, the main reservoir in the basin, was designed with flood control, water supply and irrigation uses in mind, but as yet has no agricultural uses. Of the maximum normal pool contents of 118,400 acre feet, Oklahoma City is allocated by contract the amount of 90,000 acre feet for municipal supply (OWRB, 1976).

The basin was divided into six subbasins defined by seven stream gauges on the main stream. The subbasins were numbered B11 through B16. There were a total of twelve hydrologic data sites used in the basin (10 stream gauges and 2 lake contents) and twenty meteorologic data sites

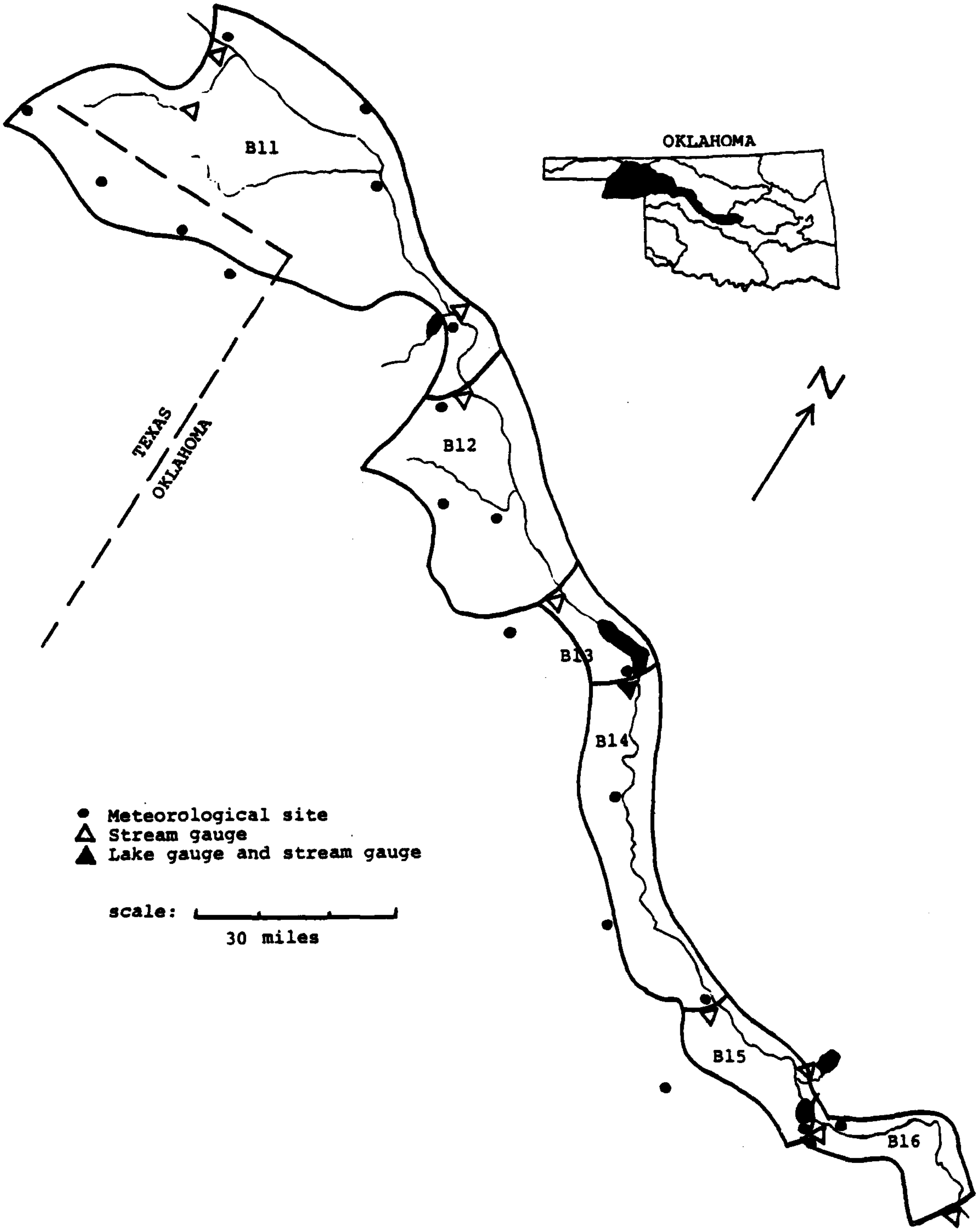

Figure 18. North Canadian River basin, from Beaver, OK to Harrah, OK.

(precipitation and temperature). Table 1 lists the hydrologic and meteorologic sites in the basin.

3.3.2 North Fork of the Red River

The North Fork of the Red River originates in Carson County, Texas, some seventy miles west of the Oklahoma-Texas border. It flows eastward to Sayre, Oklahoma and then southeastward and south through Headrick, Oklahoma where the basin for this study (Figure 19) terminates (OWRB, 1976).

The North Fork is used primarily for agricultural purposes, mainly through storage and releases at Altus Lake to the canal system below. The capacity at spillway crest is over 134,000 acre feet. The city of Altus is allocated 4,800 acre feet for municipal supply but the bulk of the storage (over 85,000 acre feet) is allocated to the Lugert-Altus Irrigation District for irrigation (OWRB, 1976).

The basin was divided into four subbasins defined by four stream gauges on the main stream and numbered B21 through B24.

The basin contained one gauged reservoir, Altus Lake. There were a total of nine hydrologic data sites used in the basin (8 stream gauges and 1 lake contents) and eleven meteorologic data sites (precipitation and temperature). Table 2 lists the data sites in the basin.

Table 1. Hydrologic and meteorologic sites in the North Canadian River basin.

Station Name	Type	Subbasin
Beaver River at Beaver, OK	Riv	11
Beaver, OK	Metr	11
Fort Supply Dam, near Fort Supply, OK	Metr	11
Gate, OK	Metr	11
Laverne, OK	Metr	11
Booker, TX	Metr	11
Darrouzett, TX	Metr	11
Follett, TX	Metr	11
Perryton, TX	Metr	11
Clear Creek near Elmwood, OK	Riv	11
Wolf Creek near Fort Supply, OK	Riv	11
North Canadian River at Woodward, OK	Riv	11-12
Mutual, OK	Metr	12
Vici, OK	Metr	12
Woodward, OK	Metr	12
North Canadian River at Seiling, OK	Riv	12-13
Taloga, OK	Metr	13
Canton Dam, OK	Metr	13
Canton Lake near Canton, OK	Lake	13
North Canadian River at Canton, OK	Riv	13-14
Geary, OK	Metr	14
Watonga, OK	Metr	14
El Reno, OK	Metr	14
North Canadian River near El Reno, OK	Riv	14-15
Union City, OK	Metr	15
Lake Hefner Canal near Oklahoma City, OK	Riv	15
Lake Overholser at Oklahoma City, OK	Lake	15
Lake Overholser, OK	Metr	15
North Canadian River below Lake Overholser, OKC	Riv	15-16
Oklahoma City WSO, OK	Metr*	16
Oklahoma City Penn Avenue, OK	Metr	16
North Canadian River near Harrah, OK	Riv	16

Riv = stream gauging site
Lake = lake contents site
Metr = cooperative meteorological reporting site
* = first-order meteorological site

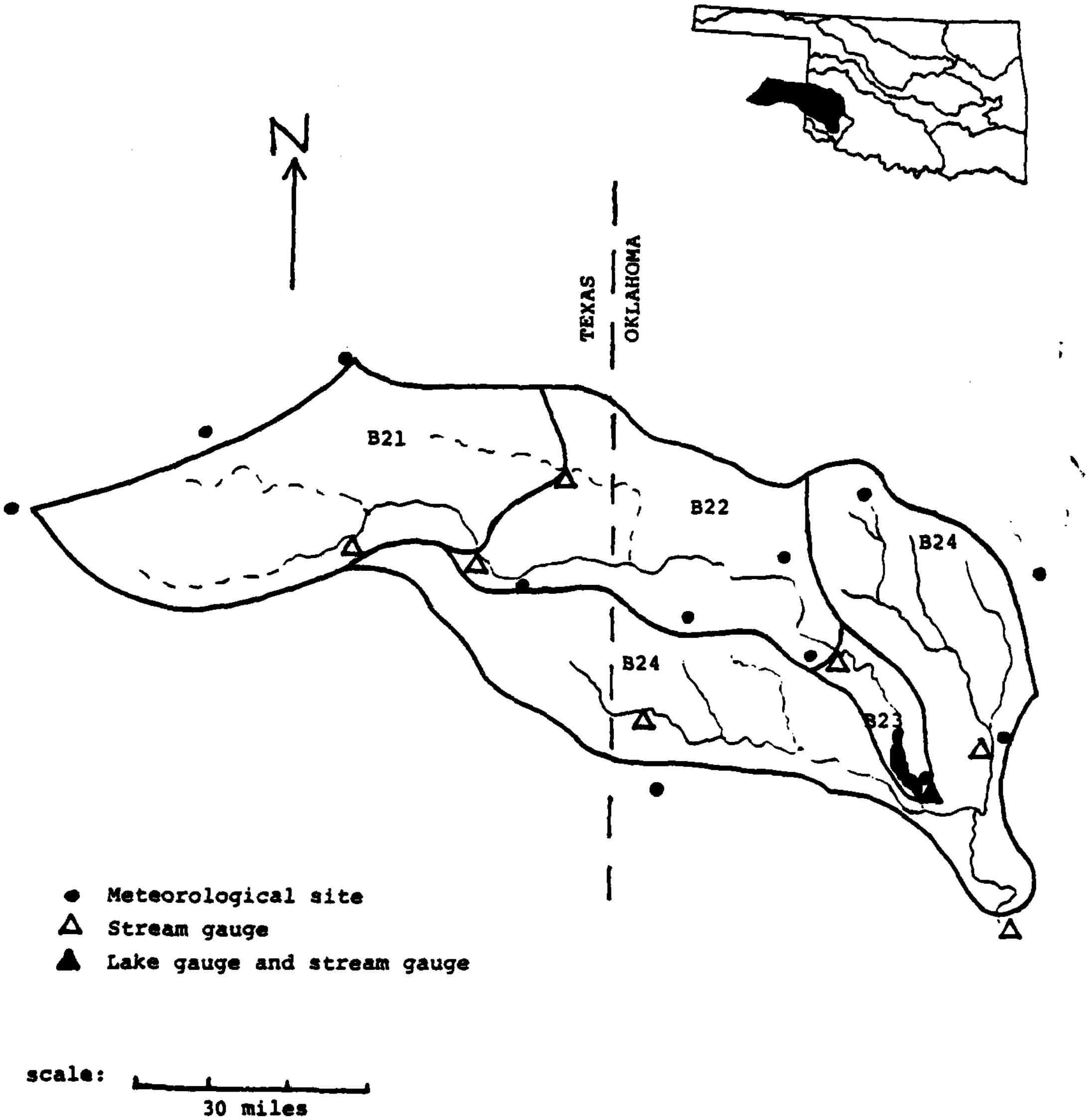

Figure 19. North Fork of the Red River basin, from headwaters in the Texas Panhandle to Headrick, OK.

Table 2. Hydrologic and meteorologic sites in the North Fork River basin.

Station Name	Type	Subbasin
McClellan Creek near McLean, TX	Riv	21
Miami, TX	Metr	21
Pampa, TX	Metr	21
Panhandle, TX	Metr	21
North Fork Red River near Shamrock, TX	Riv	21-22
Sweetwater Creek near Kelton, TX	Riv	22
Shamrock, TX	Metr	22
Erick, OK	Metr	22
Moravia, OK	Metr	22
Sayre, OK	Metr	22
North Fork Red River near Carter, OK	Riv	22-23
Lake Altus at Lugert, OK	Lake	23
North Fork Red River below Lake Altus, OK	Riv	23-24
Cordell, OK	Metr	24
Elk City, OK	Metr	24
Hobart, OK	Metr	24
Vinson, OK	Metr	24
Elm Fork of North Fork Red River near Carl, OK	Riv	24
Elk Creek near Hobart, OK	Riv	24
North Fork Red River near Headrick, OK	Riv	24

Riv = stream gauging site
Lake = lake contents site
Metr = Cooperative meteorological reporting site

CHAPTER IV

DATA AND METHODS

4.1 Sources of Original Data

4.1.1 Hydrologic Data

4.1.1.1 Source. Original hydrologic data were obtained from the National Water Data Storage and Retrieval System (WATSTORE), which is managed by the U.S. Geological Survey (USGS) in Reston, Virginia. The WATSTORE database resides on historical tape and on-line disc storage at the USGS computer facility (USGS, 1974). The database was accessed over telephone lines using an editing language called "WYLBUR." "WYLBUR" allows one to request information, have it stored for retrieval or previewing on a local terminal and then printed on a remote high-speed printer. In this case the high-speed printer at the USGS Water Resources Division in Oklahoma City was used.

4.1.1.2 Original data. Thirty years of hydrologic data for this study were obtained on magnetic tape from the WATSTORE Daily Values File. They consisted of daily values of stream flow and lake contents for calendar years 1951 through 1980, for all stations in Oklahoma and those in Texas which were within the study basins. The data were in water year format (1 Oct - 30 Sep). Stream flow data were twenty-four hour mean values, reported in cubic feet per second (cfs). Lake contents data were

predominantly once daily instantaneous readings taken at 2400 local standard time (LST). However, in a few cases, the values were twenty-four hour means. All lake data were reported in acre feet (AF).

4.1.1.3 Further data available. In addition to the Daily Values File information obtained for this research, other types of daily information are available, such as stream gauge heights, lake levels and so on. There are other WATSTORE data files that contain information for water quality, groundwater and peak flow information. They are available for all areas of the United States.

4.1.2 Meteorological Data - Oklahoma

4.1.2.1 Source. The Oklahoma meteorological data for this study were obtained from the Oklahoma Climatological Survey (OCS). The data were part of the historical record of Oklahoma Cooperative Reporting Stations. Other information obtained from the OCS was derived from the basic set of precipitation and temperature data.

4.1.2.2 Original data. The thirty years of Oklahoma meteorological data for this study were obtained on magnetic tape. They consisted of weekly values for precipitation, runoff, evapotranspiration, potential evapotranspiration and soil moisture for 1951 through 1980. The soil moisture values were weekly averages; the others weekly totals. These data were derived from the basic OCS cooperative precipitation and temperature records in basically two steps. First, missing data were filled in using a space-time interpolation technique which maintained the long-term statistical characteristics of the variables. Then, the data were averaged and derived quantities were calculated; these included the runoff, evapotranspiration, potential evapotranspiration, soil moisture and

soil moisture recharge used in this study (E. J. Cooter, 1981, personal communication).[6] The hydrologic accounting system used to calculate these "derived" variables follows Palmer (1965) and is described in Appendix A. Hill (1974) used a similar two-layer model to calculate weekly soil moisture for Kentucky.

4.1.2.3 Further data available. Further data of this type include daily precipitation and maximum and minimum temperature for almost 300 cooperative stations in Oklahoma. Some station records begin as early as 1900; most are available since 1947. These data are in either "space" or "time" formats. That is, all station data within a prescribed space may be selected, or all data for one station for a given time period (date or range of dates) may be selected. Additionally, weekly values for twenty-five derived variables are available for as long as records exist. These derived variables include soil moisture, potential evapotranspiration, evapotranspiration, runoff, Palmer Drought Index (PDI), Crop Moisture Index (CMI), and heating degree days. All of the above data are available through the OCS.

4.1.3 Meteorological Data - Texas

4.1.3.1 Source. The Texas meteorological data for this study were obtained from the Texas Natural Resources Information System (TNRIS), Austin, Texas. The data are from a portion of their cooperative reporting network.

4.1.3.2 Original data. Thirty years of daily precipitation and maximum and minimum temperature data (1951-1980) were obtained on magnetic

[6] Ellen J. Cooter, Assistant State Climatologist for Oklahoma, Oklahoma Climatological Survey, Norman, Oklahoma.

tape from TNRIS. Most stations in the selected basins have fairly complete records for precipitation (greater than 90 percent daily observations present). However, only about one half of the stations report temperature. This necessitated an editing and interpolation step later in the study.

4.2 Derived Data Sets

4.2.1 General

The process of going from the original data sets to the "final" data set involved considerable computer manipulation of large volumes of data and required numerous assumptions. The assumptions made in this derivation process are crucial to both the results and to any future amplification of this or similar studies. Consequently, they are described in detail.

The original data sets, as described above, consisted of thirty years (1951-1980) of daily values for five variables; precipitation, maximum and minimum temperature, stream discharge and lake contents. The new data set was derived in basically two steps, and with two purposes in mind. Step one in the derivation was to aggregate the daily values to calculate additional variables. The first purpose in the aggregation was to decrease the large fluctuations encountered in working with daily data but, on the other hand, to maintain sufficient resolution so that the derived data could be useful in different applications, such as drought studies, municipal and industrial planning, weather modification studies and agriculture. The second constraint in aggregation was to maintain the ability to relate findings here with existing studies in

agriculture, drought and so forth (e.g., Eddy and Cooter, 1978). With these stipulations in mind weekly aggregation was selected.

4.2.2 Aggregation of Original Data to Weekly Values

4.2.2.1 Hydrologic variables. The original hydrologic variables, stream discharge and lake contents, were in water year format (1 Oct - 30 Sep), but were reformatted to calendar years for consistency with meteorological data. Data were stratified into three groups; the study areas of the North Canadian basin, the North Fork of the Red River basin and selected sites in each of the ten primary river basins in Oklahoma. The sites in the primary river basins were selected based on the completeness of their records and their location in the basin. For example, a stream station was preferable if it was not too distant upstream or downstream from the reservoir selected. Weekly aggregate values and long-term means were then computed. Total weekly discharge (in cfs) was used for lake sites. To convert to consistent units, the stream discharge was converted to acre feet per week after Linsley et al. (1975).

4.2.2.2 Meteorological variables - Oklahoma. E. J. Cooter (1981, personal communication) had previously computed total weekly precipitation for all the Oklahoma cooperative stations. The weekly precipitation values for stations in the two study basins were extracted from tape and long term averages of total weekly precipitation were calculated.

4.2.2.3 Meteorological variables - Texas. The meteorological data for the portion of the study basins in Texas were available only in raw form (i.e., daily values for precipitation, maximum and minimum temperature) as described earlier. This required a multi-step process to

clean, format and fill in missing data. First, total weekly precipitation and average weekly temperature were computed for each station. If more than three days of any given week were missing the weekly value was stored as missing. Then, since continuous data were required to compute the derived variables (e.g., runoff), the missing data were replaced with interpolated values. Due to the small number of stations involved (eleven) the data were interpolated manually. There were few missing precipitation observations, however, several stations did not report any temperatures, and this required considerable interpolation and editing. Then, long-term weekly means were computed.

4.2.3 Computation of Basic Variable Set

To this point the original data had been cleaned, reformatted, missing values interpolated and means calculated. However, no new variables had been computed. It remained to calculate required new variables, obtain mean values for each subbasin from the individual station values and finally, ensure units were consistent. The derivation of each of the ten variables comprising the "basic variable set" is discussed below.

4.2.3.1 Precipitation. Total weekly precipitation for all stations in each subbasin were arithmetically averaged to obtain one value for each subbasin for each week. These data were then converted from inches to acre feet using the area of each subbasin.

4.2.3.2 Runoff, soil moisture, evapotranspiration. The weekly values for runoff, soil moisture and evapotranspiration for each station in Oklahoma had been previously calculated from the original Oklahoma data by E. J. Cooter. However, for Texas stations these variables were computed as part of this study using a simplified Thornthwaite hydrologic

accounting system (see Appendix A). As with precipitation, the values for individual stations in each subbasin were arithmetically averaged and then converted to acre feet. The runoff and evapotranspiration values were total weekly acre feet; the soil moisture was average daily acre feet for the week.

4.2.3.3 Lake contents. Since each subbasin contained no more than one lake, no areal averaging was required. Further, the units were reported as acre feet so no unit conversion was necessary. The average daily value for the week was used.

Daily contents information were available through WATSTORE for Altus and Canton Lakes. However, daily data were not available for the third lake, Lake Overholser. Lake Overholser, in subbasin B15, is used for municipal and industrial water supply for Oklahoma City and is managed by the Oklahoma City Water Department. Month-end readings from the Water Resources Data for Oklahoma series (for example, USGS, 1981) were used with each week of the month assumed to have the same contents as the month-end value. Due to the scale of this study and the lack of available daily or weekly data it was considered better to use these approximated values, rather than omit the lake entirely.

4.2.3.4 Lake evaporation. Lake evaporation can be measured using any of four basic methods; water budget studies, energy budget studies, mass transfer, or lake-to-pan relationships (USDA, 1977). However, daily or weekly lake evaporation information, from any method, was not available through WATSTORE. Since lake evaporation can play an important role in the total hydrologic budget, it must be considered, even if it is estimated. According to Viesman et al. (1977) "the mean rate of lake

evaporation in arid and semiarid regions is often in excess of the local precipitation depth for that area. As a result, significant quantities of water are lost to those areas for beneficial use."

To estimate the evaporation from the three lakes in the two study areas the following approximation was made. Monthly lake evaporation values for Lake Hefner (USGS, 1952) were plotted. A smooth curve was drawn through the points and weekly evaporation values (in inches) were extracted (see Figure 20).

The average lake contents (calculated in a previous step) were converted to average surface area (in acres) using information from the Oklahoma Water Atlas (OWRB, 1976). Total yearly lake evaporation information was obtained from the same source and then weekly lake evaporation (in acre feet) was calculated using the following approach (after Viesman et al.. 1977):

$$EAF = EIN * A * C \tag{4.1}$$

where EAF is weekly evaporation in acre feet, EIN is weekly evaporation in inches, A is surface area in acres and C is the conversion from inches to feet. Since the long term average weekly contents were used, the values calculated varied from week to week, but the annual value was constant.

4.2.3.5 Stream inflow, outflow, contents. Stream inflow and outflow values were taken directly from the total weekly stream flow at the appropriate gauge. For example, the value from the gauge at El Reno, Oklahoma would be used as outflow from subbasin B13 and inflow to subbasin B14. Stream contents, however, were handled differently.

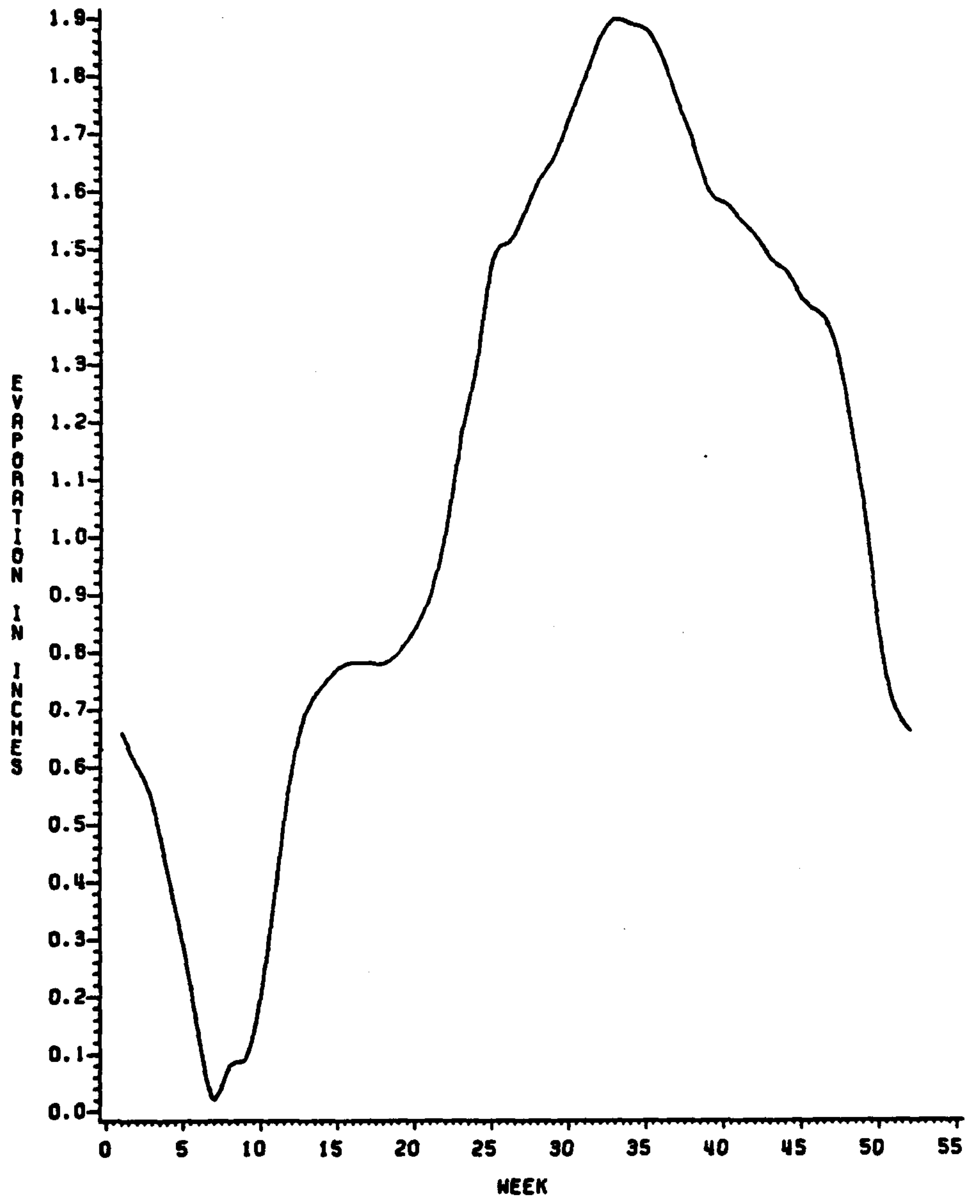

Figure 20. Weekly evaporation for Lake Hefner, OK. Data from May 1950 through August 1951 (After USGS, 1952); evaporation in inches per week.

The weekly inflow measured by the gauge at the beginning of the subbasin, and any gauges on the tributaries within the subbasin were multiplied by a time lag factor to arrive at the average daily amount of water in the stream for the week. The factor was computed using the distance (in stream-miles) of the input gauge to the exit gauge and an average speed of flow of 3.5 feet per second (fps). For example, the factor for subbasin B11 (input at Beaver, outflow at Woodward) was calculated in two steps.

a. The number of miles the average flow would travel in one day was computed. This was approximately 57 miles.

b. Then, the stream miles from Beaver to Woodward were divided by the distance the flow would travel in a day, obtaining a time lag factor with units of days. In this example the factor is 2.9 days (163 miles/57 miles per day).

The time lag factor times the average daily flow then approximates the average daily stream contents for the week. However, one assumption involved in this calculation merits explicit discussion.

The use of an average flow speed is a gross approximation at best. The speed of flow in a particular subbasin will vary considerably depending on the volume, whether it is base flow or a flood crest, the condition of the stream bed (wet, saturated) and undoubtedly other factors as well. The speed will also vary from subbasin to subbasin depending on the channel slope, composition and geometry. However, the purpose and scope of this study were such that using complex hydrologic modeling to estimate this parameter more accurately was deemed unnecessary.

4.2.3.6 Stream evaporation term. The stream evaporation term is actually additional evaporation from the stream, stream bed, the surrounding alluvium deposits as well as the riparian vegetation. The actual evapotranspiration for the entire subbasin is reflected in the evapotranspiration term. However, for most of the year (March through November) the actual evapotranspiration is less than the potential evapotranspiration. For example, see Figure 21. The stream bed and surroundings were assumed to give up water at the potential rate, consequently, the stream evaporation term is that additional evapotranspiration.

Two basic assumptions in the creation of this variable are worth noting. First, the near-stream environment is assumed to give up water at the potential evapotranspiration rate year-round. This appears to be an acceptable assumption (Nicks, 1982, personal communication) based largely on the fact that much of the stream flow in western Oklahoma is subsurface. There would be, therefore, a source of moisture for evaporation at the potential rate even if no surface flow existed. The second assumption involves defining the near-stream environment. In this case, the immediate stream bed and the surrounding alluvium and terrace deposits were used. The area of these deposits was determined using a square mile grid overlaying hydrologic/geologic maps from the Oklahoma Geological Survey (OGS) Water Atlas series and Geologic Atlas of Texas series. (OGS, 1975, 1976, 1977, 1978 and Bureau of Economic Geology, 1969, 1970).

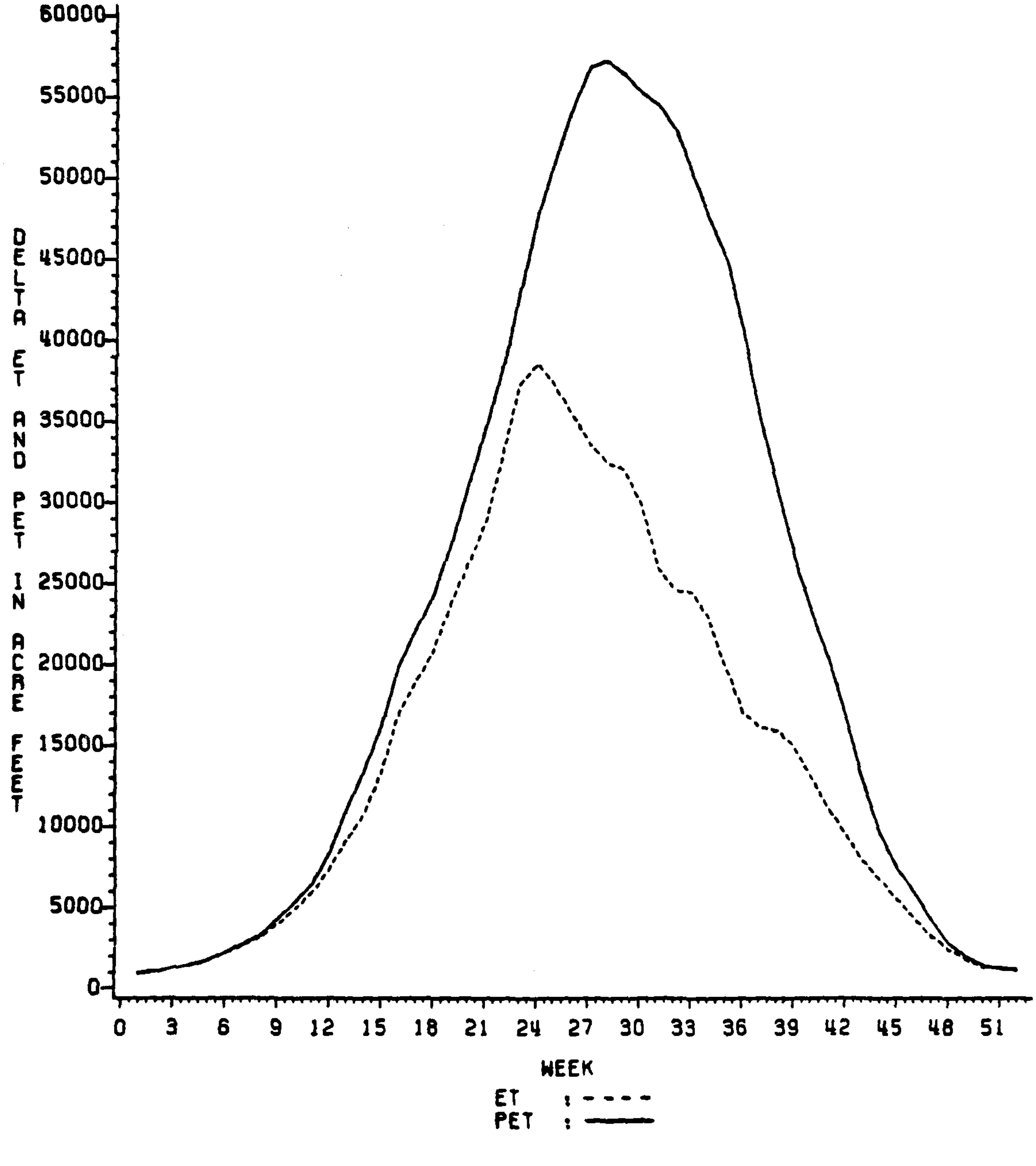

Figure 21. Potential (PET) and actual (ET) evapotranspiration; long-term weekly means for subbasin B12 of the North Canadian River; delta, ET and PET in acre feet per week.

4.3 The Hydrologic Balance

4.3.1 Balance Equation and Channel Loss

Many authors cite the need for a balance between hydrologic input and output in a basin. For example, Mather (1974) expresses it as

$$NBS = RO + P + E \tag{4.3}$$

where NBS is net basin supply, RO is runoff, P is precipitation over lakes and rivers and E is evaporation. However, for the purposes of this study the formulation by Nicks (1982, personal communication) was a better point of departure. It can be expressed as

$$\Delta S = P + SM + BI - D \tag{4.4}$$

where ΔS is the change in storage in the basin, P is precipitation, SM is soil moisture, BI is inflow into the basin, and D is demand. Demand, which is also called consumptive use, encompasses evapotranspiration, lake contents, lake evaporation and channel loss. (Channel loss, which is basically stream loss to or gain from the groundwater aquifers, is defined more completely later in this section.)

To examine the state of balance in each subbasin in light of Equation (4.4) and given the basic variable set developed previously, the following balance equation was developed

$$RO - SE - CL = (SO-SI) + \Delta LC \tag{4.5}$$

where RO is runoff, SE is the stream evaporation term, SO is stream outflow, SI is stream inflow and ΔLC is change in lake contents, all discussed earlier in this chapter. The remaining term, CL, is channel loss. In Equation 4.5 channel loss is the unknown. By rearranging terms

Equation 4.5 becomes

$$CL = RO - SE - SO + SI - \Delta LC \tag{4.6}$$

Channel loss is defined as positive when there is loss from the stream channel into the stream bed, banks, surrounding alluvium and aquifers. Conversely, channel loss is negative (i.e., channel gain) when there is gain into the stream, from the surrounding channel, as would be the case, for example, with groundwater discharge.

4.3.2 Sources of Error in Channel Loss

Although channel loss represents a real phenomenon, caution must be used when interpreting it as defined in the context of this study. The reason is both simple and crucial. In this research, channel loss is a balancing term and as such accounts for many things. Foremost in design, but possibly not in magnitude, it accounts for the actual two-way flow into and out of the stream bed. However, it also accounts for sources and sinks not measured (such as subterranean stream flow), errors in measurement of the basic variables (e.g., precipitation, stream flow), errors in assumptions (such as computing the stream evaporation term) and undoubtedly many more. In short, the channel loss term is an essential part of the balance equation as well as a necessary result of the assumptions and scale of the entire study.

4.4 Water Supply

4.4.1 General

Obtaining the original data (precipitation, temperature, stream discharge and lake contents), deriving the basic variable set, now with

channel loss, and producing climatologies of these variables was a first step. However, that does not speak to the research question identified, namely that there is not always enough water in Oklahoma at the times and places required. To address this question the times and magnitudes of water deficit must be identified, quantified and examined. That requires the calculation of three new variables; storage, demand and a term called delta.

4.4.2 Storage and Demand

Storage is defined as

$$S = SM + LC + CC \tag{4.7}$$

where SM is soil moisture, LC is lake contents and CC is channel contents. Channel contents is the sum of stream contents (SC) and net channel gain (-CL). Demand is

$$D = ET + SE + LE + CL \tag{4.8}$$

where ET is evapotranspiration, SE is the stream evaporation term, LE is lake evaporation and CL is channel loss. It is important to note that the storage equation does not take into account explicitly the storage contribution from the subsurface aquifers. This is implicit, however, in the channel loss (gain) term. Storage is water available for use, although not all parts of it are equally available. Lake and stream contents are essentially immediately available. However, soil moisture is not immediately available _in toto_ and probably more importantly its availability varies profoundly depending on its intended use. It is most readily available to crops planted in the soil, or to evapotranspiration, but it is largely not available for direct use by man (e.g., for municipal

water, or irrigation). Soil moisture is the dominant factor in the storage calculation if there is not a lake in the subbasin; when a lake is present soil moisture and lake contents are usually of the same magnitude. The largest component of demand is evapotranspiration. Stream evaporation and lake evaporation are usually tne same order of magnitude and from one to three orders of magnitude smaller than evapotranspiration (see Table 3). The average yearly order of magnitude of channel loss is very small because the positive and negative components tend to cancel.

Table 3. Normalized long-term magnitudes of storage and demand, by subbasin; units are acre feet.

SB	P	RO	SM	ET	SI	SO	SC	LC	LE	SE
11	3	2	4	3	0	1	0			1
12	2	1	3	2	1	1	0			1
13	1	0	2	1	1	1	1	2	0	0
14	2	1	3	2	1	1	1			1
15	1	1	2	1	1	1	0	2	0	0
16	1	1	2	1	1	1	0			1
21	3	2	4	3	1	1	0			2
22	4	3	5	4	1	2	0			2
23	1	0	2	1	1	0	0	2	0	0
24	2	1	3	2	0	1	0			1

NOTE: The column headings have the same meanings as in the text.

P = precipitation
RO = runoff
SM = soil moisture
ET = evapotranspiration
SI = stream inflow
SO = stream outflow
SC = stream contents
LC = lake contents
LE = lake evaporation term
SE = stream evaporation

4.4.3 Delta

By expanding Equation (4.4) to include the terms included under consumptive use (or demand), we obtain

$$\Delta S = P + SM + BI + LC - ET - LE - CL \quad (4.9)$$

We can also combine Equations (4.7) and (4.8) following (4.4), and obtain

$$\Delta S = SM + CC + LC - ET - SE - LE - CL \quad (4.10)$$

In addition to the terms which are the same in (4.9) and (4.10), we can equate basin inflow (BI) to channel contents (CC), and include the stream evaporation term (SE) in (4.10) as part of actual evapotranspiration (ET) in (4.9). The only difference in the two equations now is that (4.9) has an explicit precipitation term; (4.10) does not. At this point it would be helpful to consider an example of how the hydrologic accounting system used in this study (Appendix A) handles precipitation.

Figure 22 illustrates schematically what can happen to precipitation in three separate situations. In this example the evapotranspiration (ET) requirement is five inches, and the soil moisture (SM) recharge requirement is three inches.

In Figure 22.A, all the precipitation is used to satisfy evapotranspiration. In Figure 22.B, ET is satisfied and two of the three inches needed to recharge the soil moisture table are supplied. Note, that not until both the ET and the SM recharge requirements are satisfied, as in Figure 22.C, will any runoff occur. It must be emphasized that the above example illustrates how the hydrologic budget used in this study handles precipitation, evapotranspiration, recharge and runoff. In actuality, some runoff may occur before the ET and SM requirements are

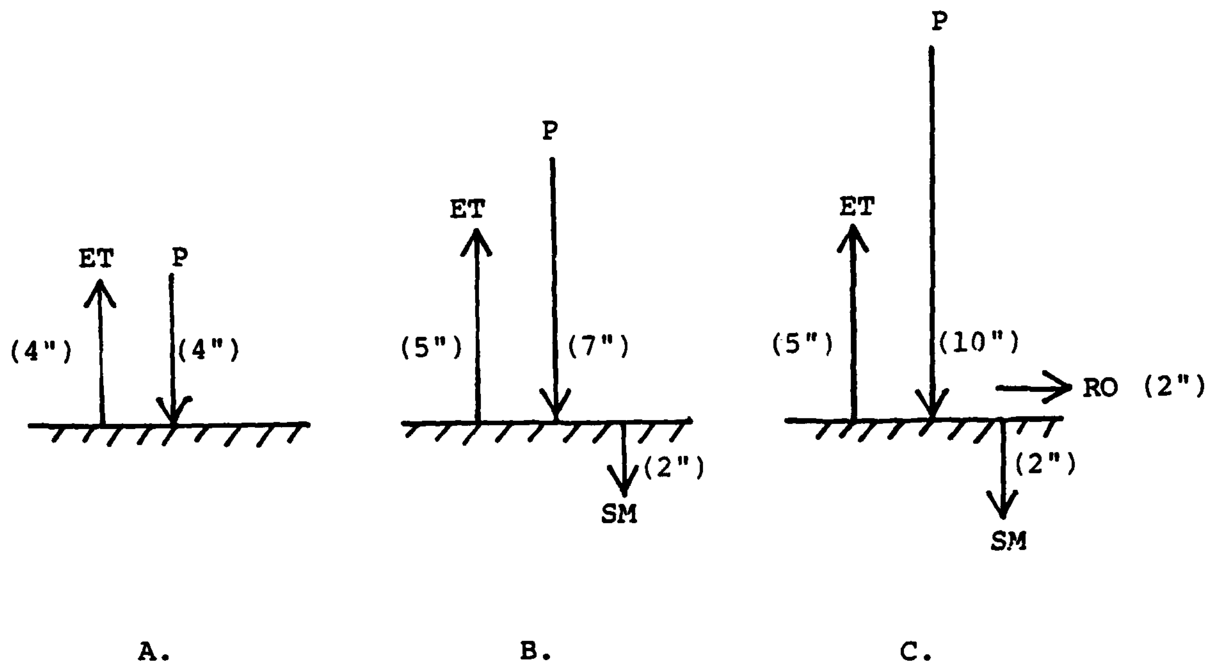

Figure 22. Schematic partitioning of precipitation (P), evapotranspiration (ET), soil moisture (SM) and runoff (RO) following the hydrologic accounting system (Appendix A).

fully met. This could occur, for example, if the precipitation rate was so heavy that it exceeded the infiltration rate of the soil.

Returning to Equations (4.9) and (4.10), we see that precipitation is included explicitly in (4.9) and implicitly in both (4.9) and (4.10) through the runoff in the channel loss term (see equation (4.6)). In order to make Equation (4.10) comprehensive, a new term must be added. This term, called delta, is the direct contribution to evapotranspiration by precipitation. That is, it is the amount of precipitation that directly satisfies evapotranspiration before being available to either soil moisture or runoff. Delta, then, is defined as

$$\text{Delta} = P - R - RO \tag{4.11}$$

where P is precipitation, R is soil moisture recharge, and RO is runoff.

By keeping delta separate and not adding it to the equation for storage (4.7) we can isolate the key role precipitation plays in the storage-demand picture. Some of the ramifications of this are discussed in the next chapter.

CHAPTER V

RESULTS AND DISCUSSION

5.1 Data Presentation and Filtering

The data discussed in the previous chapter are presented in this chapter in several formats; time series, percentage frequency histograms and joint frequency tables. In most cases the data are long-term (thirty years) mean values. When ranges are used they are an approximate 75 percent empirical envelope (actually, 73.3 percent). That is, approximately 12.5 percent of the values are below the bottom range and 12.5 percent above the top range. Occasionally, as in the case studies, data for individual years are also presented.

Except for an illustrative example, all subsequent data have been filtered using a Hanning type three-point filter (values: .25, .5, .25). This filtering reduces the wide week-to-week fluctuation while not changing the overall mean. The filtering process smooths the portion of these fluctuations due to the arbitrary nature of selecting the particular seven day (weekly) periods over which the data were aggregated. Figure 23 is an example of unfiltered precipitation data for subbasin B21. Figure 24 is the same data after filtering.

All of the time series use Julian weeks and throughout the discussions interesting features will often be referenced by week number. For convenience, Appendix B is a conversion from Julian week

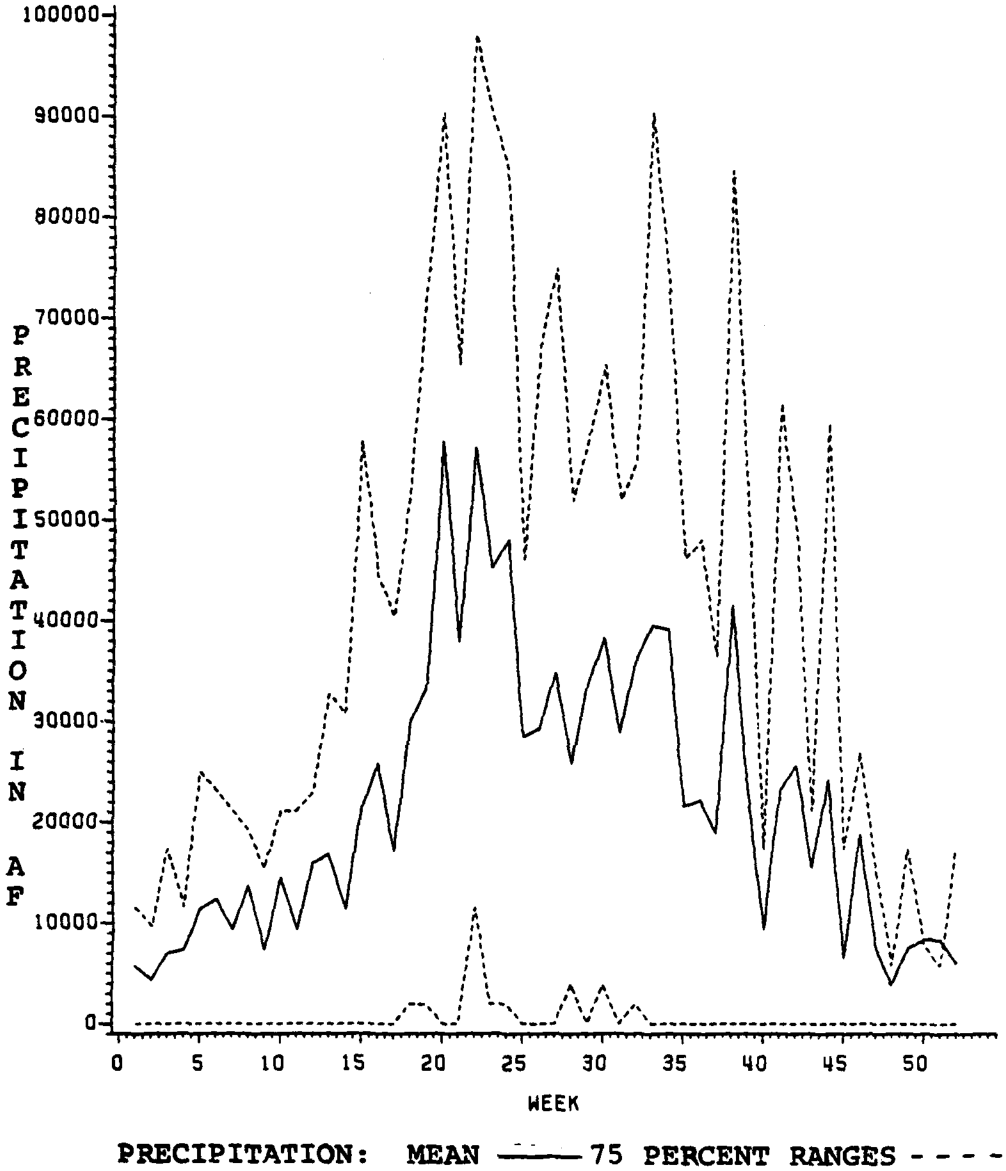

Figure 23. Unfiltered precipitation vs. time; long-term weekly means and 75 percent ranges for subbasin B21 of the North Fork of the Red River; precipitation in acre feet per week.

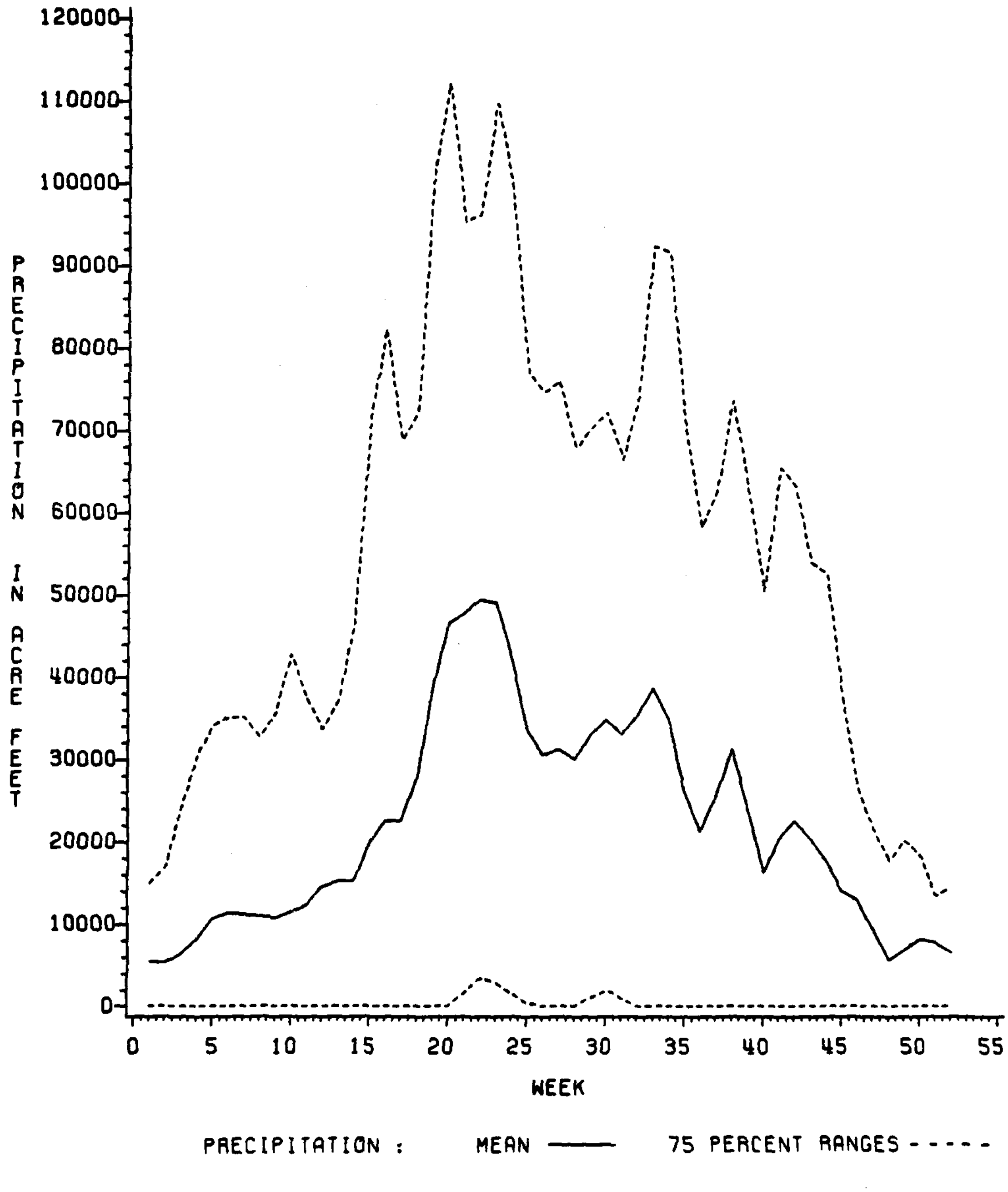

Figure 24. Filtered precipitation vs. time; long-term weekly means and 75 percent ranges for subbasin B21 of the North Fork of the Red River; precipitation in acre feet per week.

to month and date.

5.2 Characteristics of Basic Variables

In this section, time series of long-term means and 75 percent ranges for each of the ten "basic variables" (see Section 4.2.3) and channel loss will be presented. The general characteristics of each, as well as deviations from those characteristics, will be discussed and illustrated. Physical interpretation of interesting features will also be discussed. Appendix C is a complete set of time series for these variables as well as other variables which are discussed later.

5.2.1 Precipitation

The primary feature of the long-term mean weekly precipitation in the basins under study is its bimodal character. The major peak occurs between weeks 21 and 23, with a secondary peak between weeks 36 and 39. The largest peak is about 1.5 times as large as the secondary peak. Frequently one or two tertiary peaks occur between the two primary ones. Figure 25, for subbasin B24, illustrates the general characteristics found in precipitation. The two western-most subbasins (B21, B11) also show a bimodal character. However, the secondary peak occurs earlier in the year, week 34 to 35, and the primary peak is slightly smaller in comparison (1.3 times as large). Figure 26 from subbasin B21 illustrates this long-term precipitation pattern.

5.2.2 Runoff

Runoff has the most erratic range of the basic variables. The general pattern is characterized by a predominant peak in the late

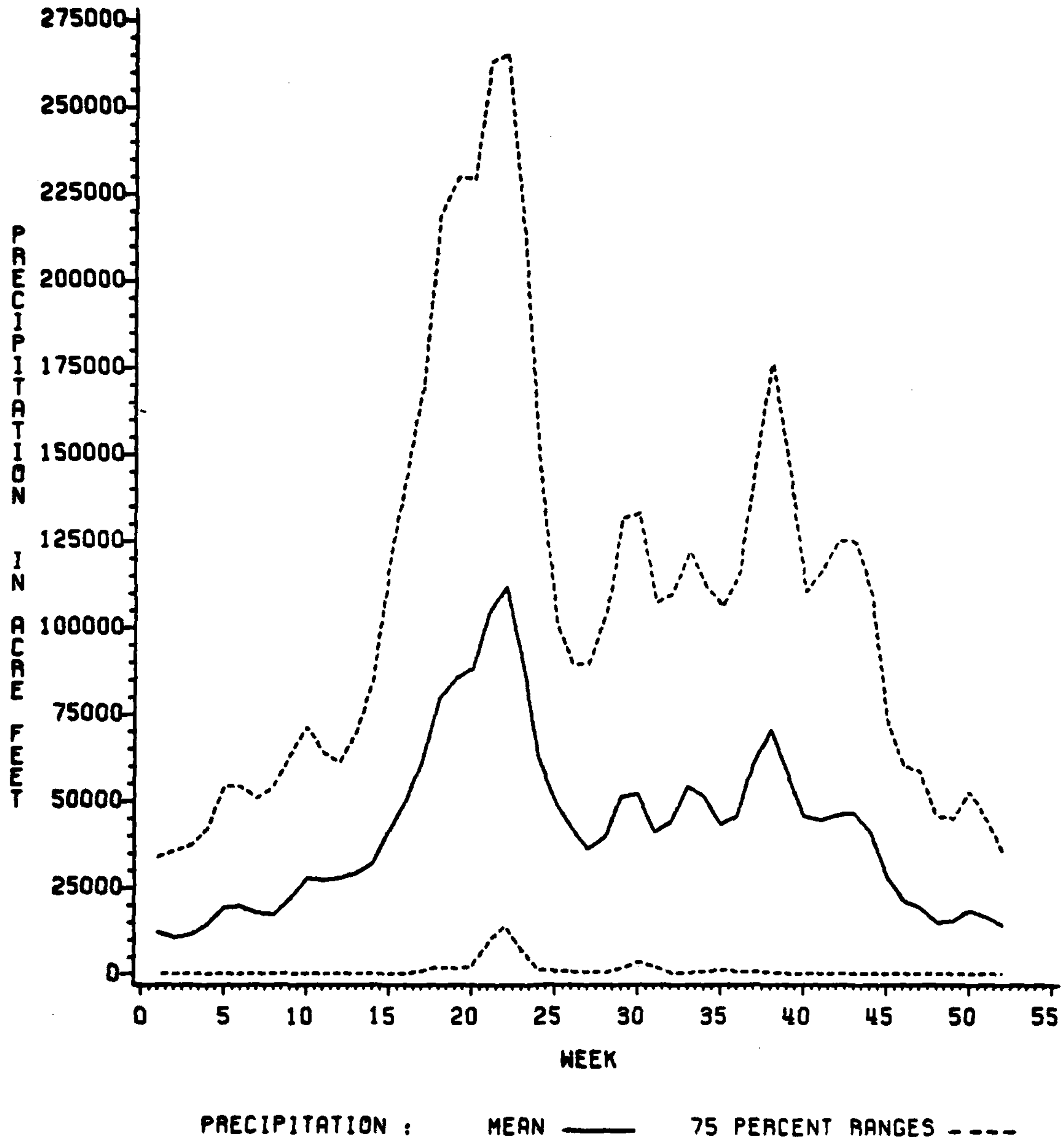

Figure 25. Precipitation vs. time; long-term weekly means and 75 percent ranges for subbasin B24 of the North Fork of the Red River; precipitation in acre feet per week.

spring, weeks 19 to 22, which corresponds well with the major precipitation peak. Figure 27 illustrates the general runoff pattern. This peak is followed by a very rapid decrease, to virtually no runoff, by the early summer (week 27). There are several reasons for this. At this time there is a rapid rise in the demands for evapotranspiration and soil moisture recharge. Also, this is the time of maximum renewed growth of natural vegetation such as long prairie grasses. The vegetation serves to retard runoff. The late summer precipitation peak is also reflected in the runoff, with a secondary peak about week 39. There is a definite change in the late summer runoff pattern as you move from west to east. In the more arid Oklahoma and Texas panhandles a smaller proportion of the precipitation is reflected in the late summer runoff, while farther east the late spring and late summer runoff are about the same proportionate share of precipitation.

A third runoff peak, which is about the same magnitude as the late summer one, occurs in early spring (week 12). However, this is not associated with an obvious precipitation peak. The reason for the runoff at this time is most probably that the soil moisture table is close to full (requires little recharge) and the evapotranspiration demands are very small. Therefore, most rainfall is translated into runoff. In fact, at this time of year, twenty to fifty percent of precipitation shows up as runoff. On the other hand, in the late spring only ten to twenty percent of precipitation is reflected as runoff, and in the late summer usually less than ten percent (and often zero) of precipitation turns into runoff. In the long-term, runoff is generally an order of magnitude less than precipitation.

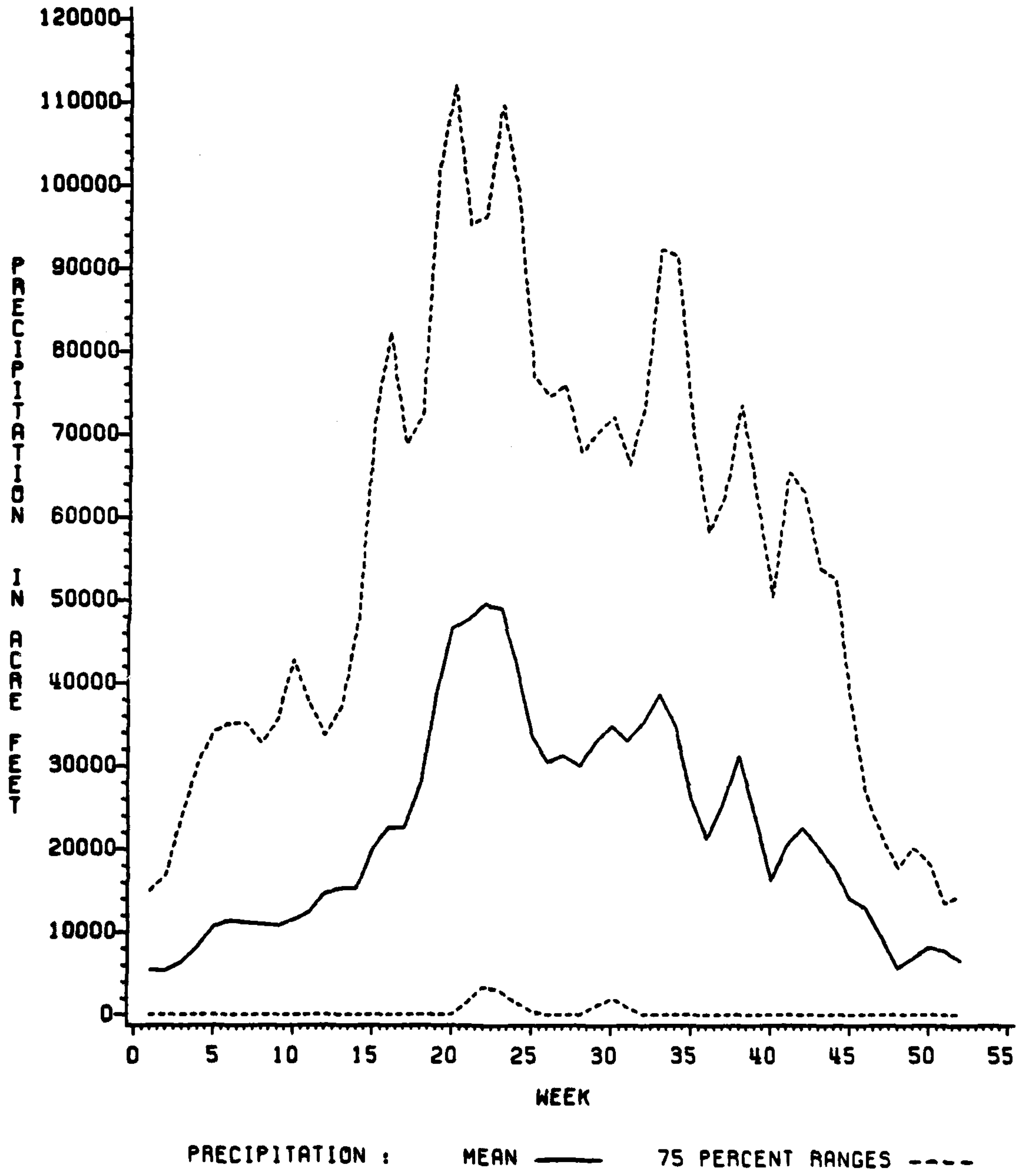

Figure 26. Precipitation vs. time; long-term weekly means and 75 percent ranges for subbasin B21 of the North Fork of the Red River ; precipitation in acre feet per week.

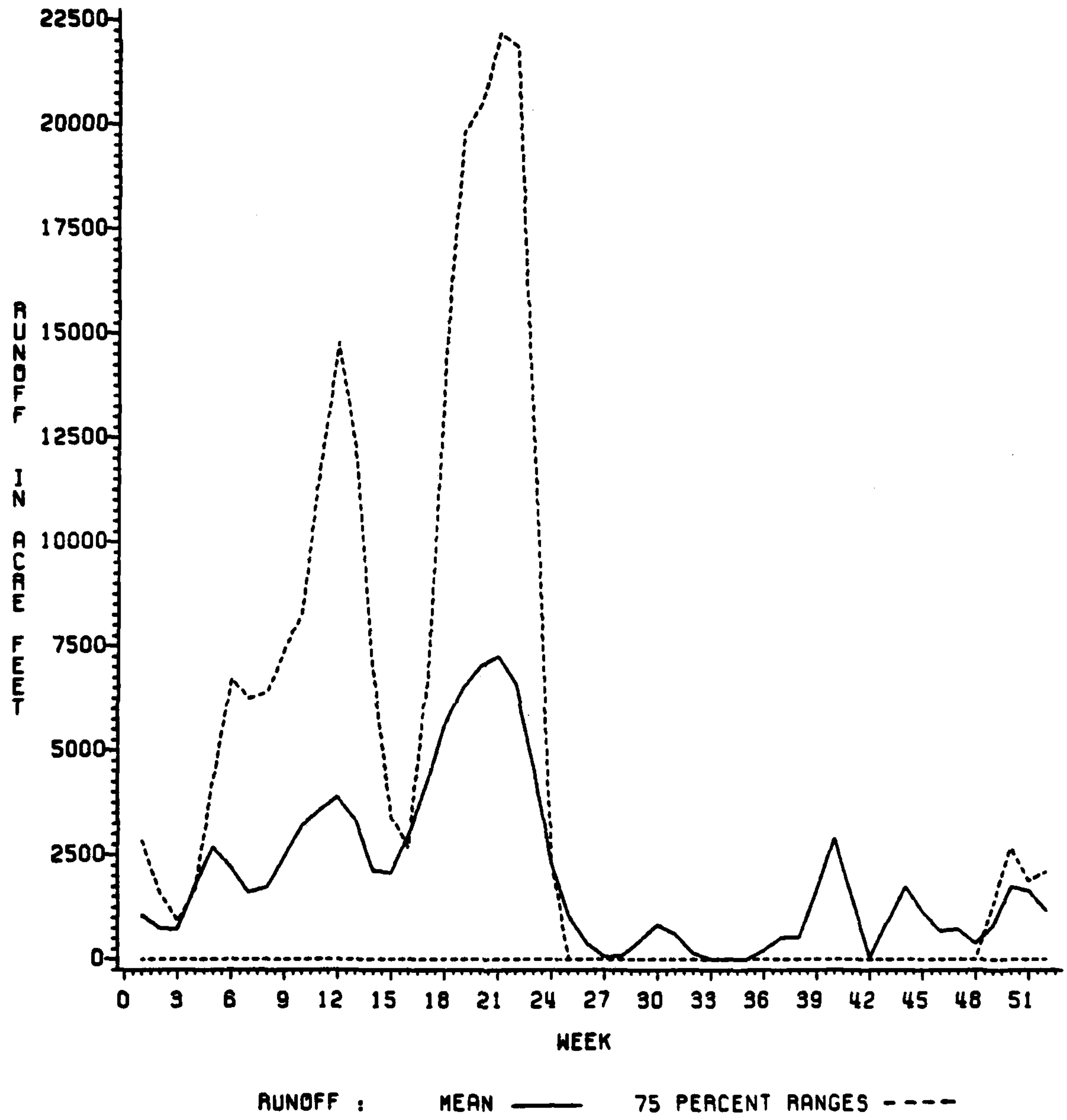

Figure 27. Runoff vs. time; long-term weekly means and 75 percent ranges for subbasin B14 of the North Canadian River; runoff in acre feet per week.

Figure 28 illustrates the only significant departure from the general runoff pattern described above. It shows a bimodal nature in the early and late spring peaks, rather than a secondary, primary relationship.

Finally, it is noteworthy that the mean runoff value is occasionally greater than the 75 percent range. This is especially true in the summer and fall. The reason is that in many of the thirty years there is no runoff for a particular week. In that case, a small number of runoff events bias the mean. This peculiar circumstance could have been masked in the time-series plots, but was left intact to emphasize the erratic nature of runoff.

5.2.3 Soil Moisture

Soil moisture is one of the two basic variables that show the least subbasin to subbasin variability (the other is evapotranspiration). In fact, the yearly pattern of soil moisture variability is remarkably similar throughout the Great Plains and lower Midwest (see for example, Eddy and Cooter, 1978). Figure 29, which is characteristic of the soil moisture patterns in the two study areas, could easily have come from Iowa or Illinois. The reason lies in similar evapotranspiration demands (following section) and in the similar synoptic regimes which produce rainfall in the late spring and late summer, instead of more uniformly year-round, as for example, in the Southeastern United States.

In each subbasin soil moisture is the largest term of the basic variables (equal to lake contents), being an order of magnitude larger than both precipitation and evapotranspiration, and two orders

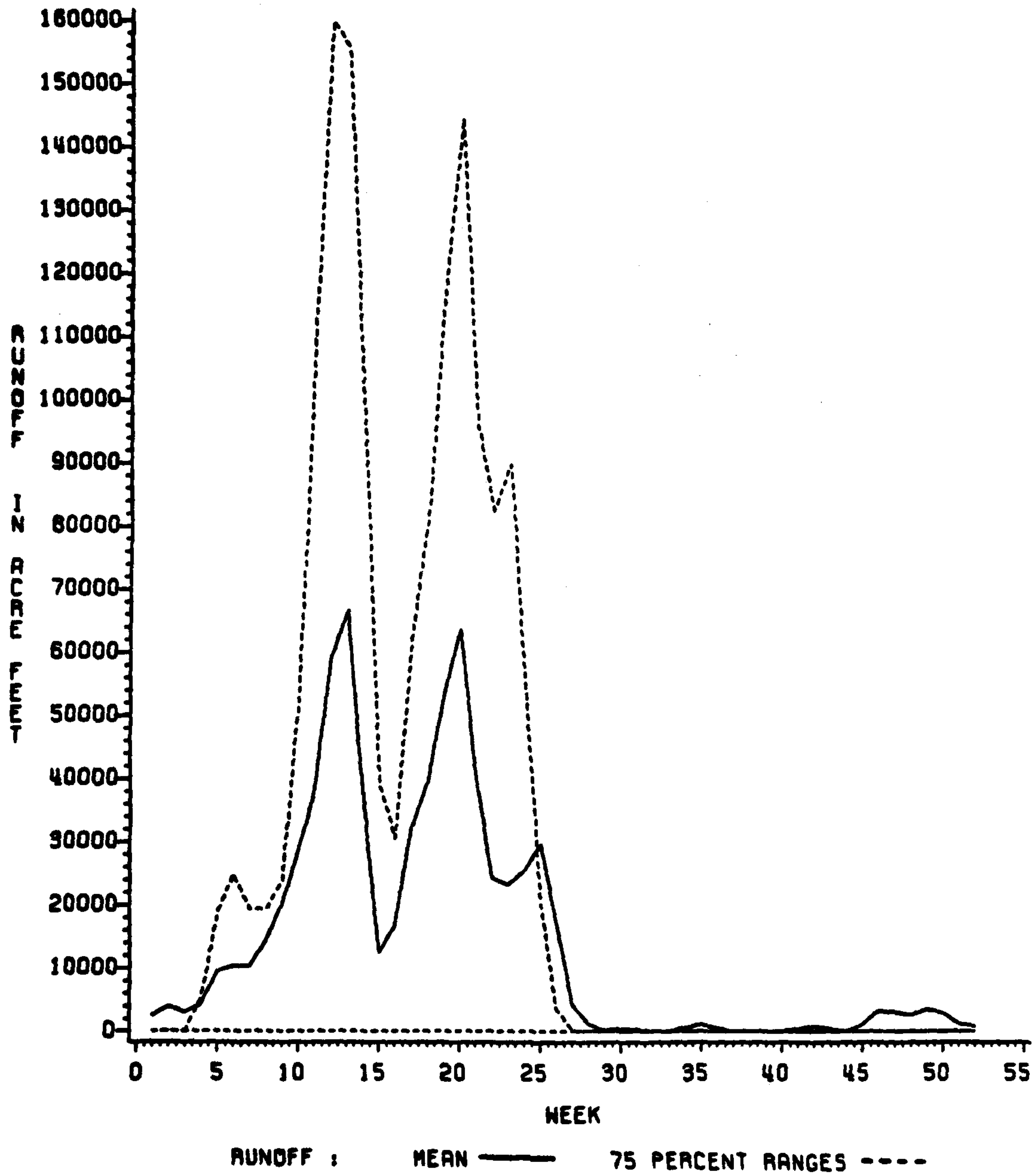

Figure 28. Runoff vs. time; long-term weekly means and 75 percent ranges for subbasin B11 of the North Canadian River; runoff in acre feet per week.

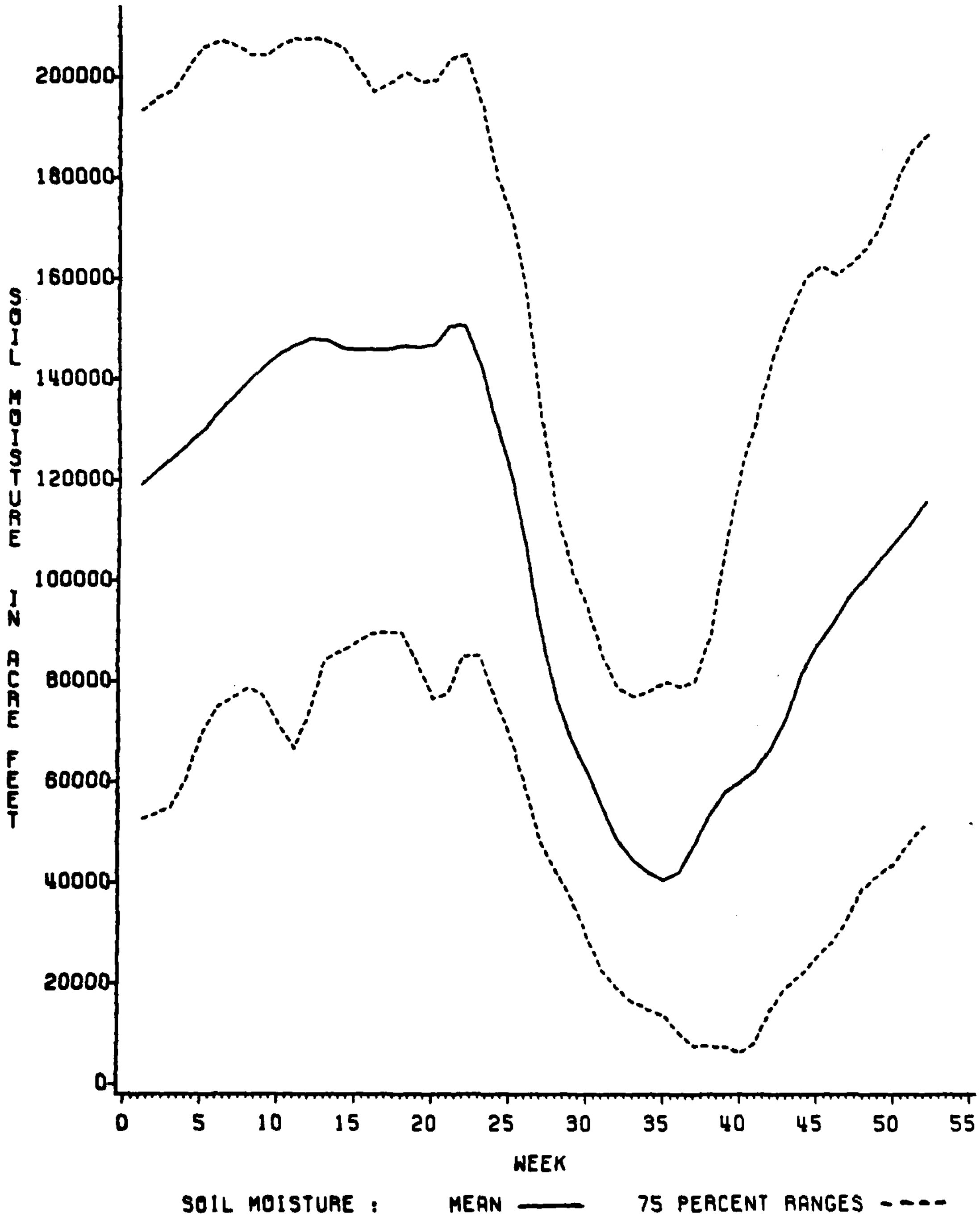

Figure 29. Soil moisture vs. time; long-term weekly means and 75 percent ranges for subbasin B14 of the North Canadian River; soil moisture in average acre feet per week.

of magnitude larger than lake evaporation or runoff.

The soil moisture builds slowly throughout the spring to a maximum in very late spring (week 23 to 24). Then, as evapotranspiration rapidly increases and late spring rains cease, the soil moisture decreases precipitously through the summer to a minimum in August (week 32 to 35). There follows a trough, with the lowest values lasting from a week, up to ten weeks in the Oklahoma panhandle (e.g., Figure 30, for subbasin B11). Then, as evapotranspiration wanes and late summer precipitation arrives, the soil moisture begins to be replenished quickly, although not as rapidly as it was depleted.

The 75 percent ranges are largest in the late fall and winter, but the summer decrease in soil moisture is remarkably consistent from year to year because of the consistency of evapotranspiration. As you would expect, the largest ranges occur farther west, as can be seen in Figure 30.

5.2.4 Evapotranspiration

Evapotranspiration is the most uniform of the basic variables from subbasin to subbasin. It is also very similar throughout the Great Plains and lower Midwest (see for example Eddy and Cooter, 1978). Actual evapotranspiration is driven by potential evapotranspiration and limited by moisture availability. The potential evapotranspiration (how much evapotranspiration would occur if moisture was not a limiting factor) is a function of temperature, wind, atmospheric humidity and solar radiation (Thronthwaite, 1948). Potential and actual evapotranspiration remain close until mid-June (week 22 to 23), but whereas

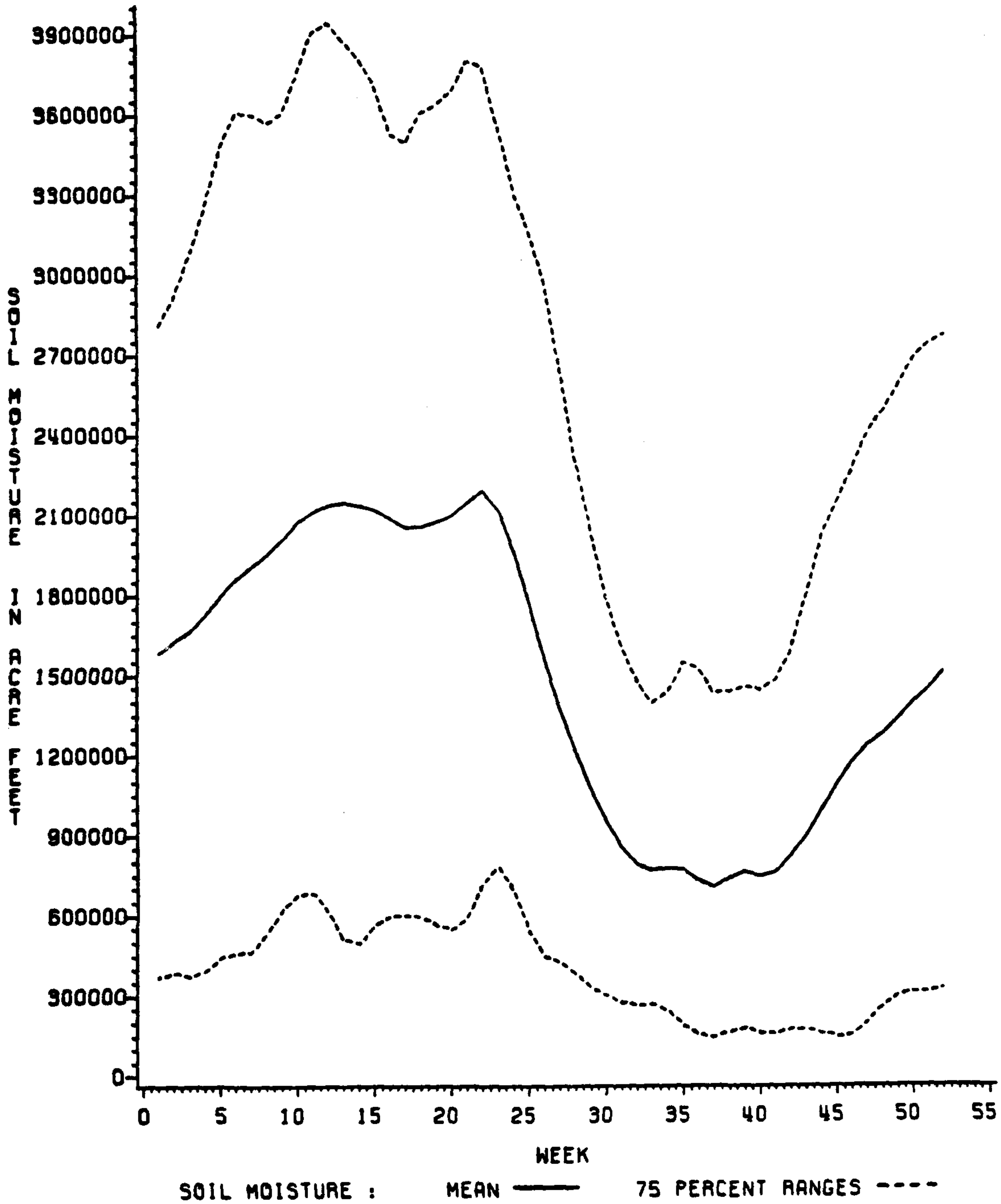

Figure 30. Soil moisture vs. time; long-term weekly means and 75 percent ranges for subbasin B11 of the North Canadian River; soil moisture in average acre feet per week.

evapotranspiration peaks by the end of June (week 25 to 26), potential evapotranspiration continues to increase until almost the end of July (week 28 to 30) (see Figure 31). Evapotranspiration reaches its peak just after the late spring *maximum* in precipitation, and then begins to decrease because of lack of moisture; the rains are over and the soil moisture reserve has, by this time, begun to decrease rapidly.

Figure 32 is typical of the evapotranspiration in the study areas. Note that the smaller the evapotranspiration (lower range), the earlier it peaks, and the larger the evapotranspiration (upper range), the later it peaks. The upper evapotranspiration range in Figure 32 closely resembles potential evapotranspiration in Figure 31. This clearly illustrates that evapotranspiration is limited by moisture availability.

5.2.5 Stream Inflow, Outflow and Contents

Two things should be noted prior to discussing the first three stream variables. First, the stream outflow from one subbasin is the stream inflow to the next basin. Remembering this will help avoid confusion when examining the full set of time-series in Appendix C. The second item to note is that the shape of stream inflow and stream contents curves will be essentially identical. This is because contents were defined as a fractional amount of the inflow (see Section 4.2.3.5). In light of the relationship between these three variables, the following discussion will generally refer to stream contents, with the understanding that the same statements could be made about stream inflow and stream outflow. If the remarks do not apply to all three,

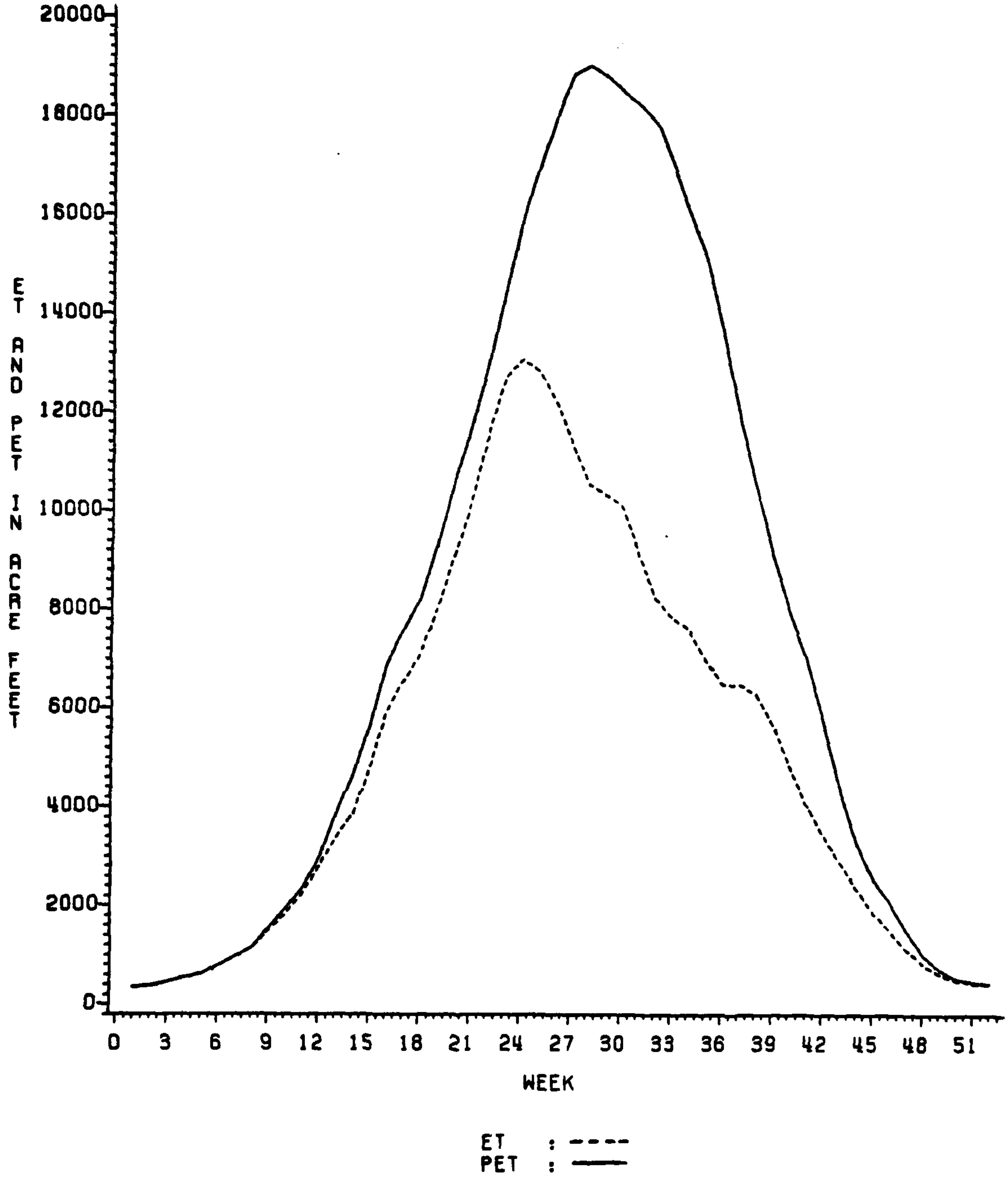

Figure 31. Evapotranspiration(ET) and potential evapotranspiration(PET) vs. time; long-term weekly means for subbasin B13 of the North Canadian River; ET and PET in acre feet per week.

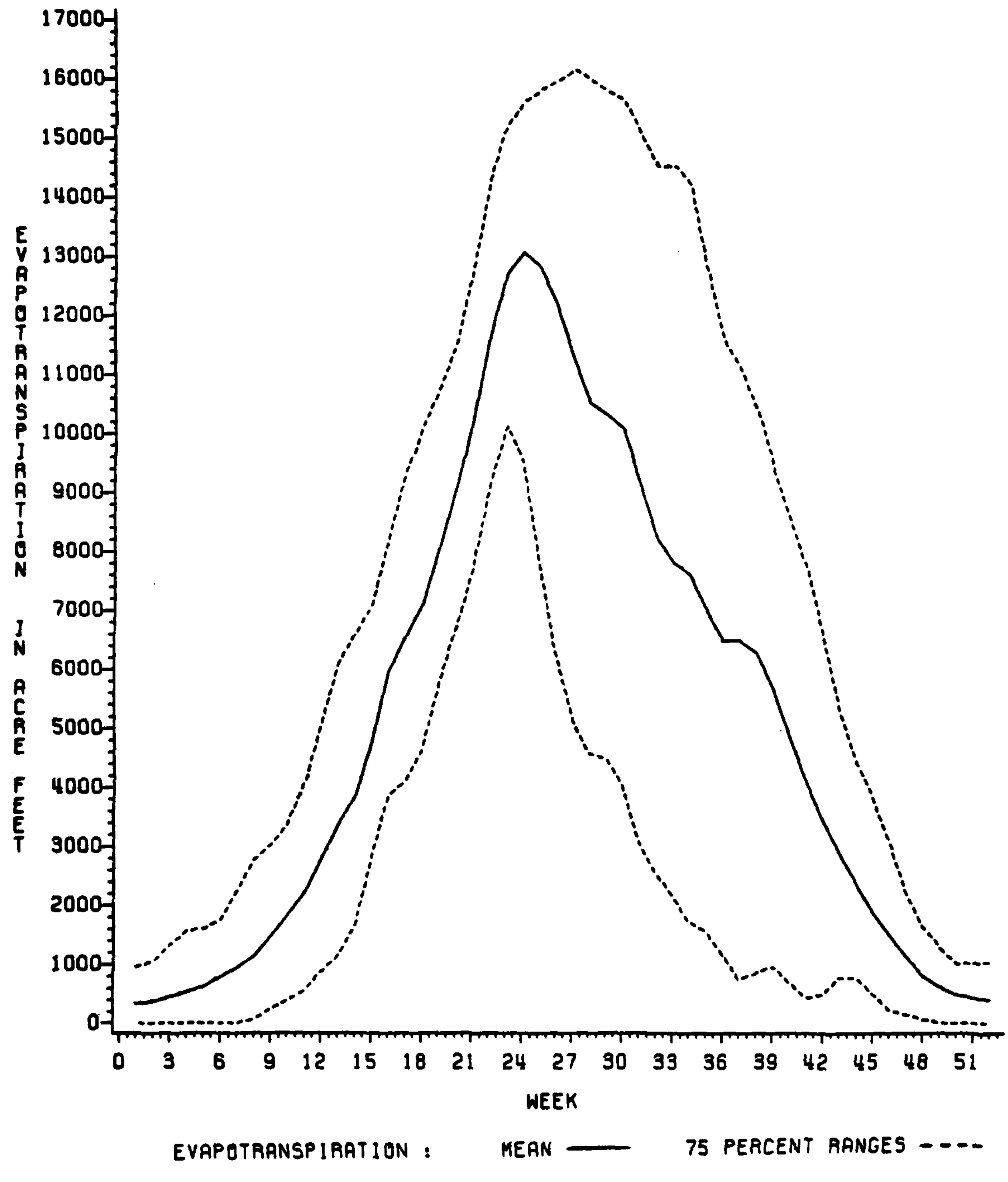

Figure 32. Evapotranspiration vs. time; long-term weekly means and 75 percent ranges for subbasin B13 of the North Fork of the Red River; evapotranspiration in acre feet per week.

that will be clearly indicated.

The stream contents patterns are produced by conditions exterior to the subbasins (that is, inflow) and changes within the subbasin, primarily precipitation as reflected in runoff. Stream contents usually has a dominate peak in the late spring (weeks 20 to 23) which corresponds with the peak runoff. Secondary peaks occur in the late summer, also corresponding to smaller runoff peaks. Figures 33, 34, and 35 from subbasin B14 (stream inflow, stream outflow, stream contents) can be compared with Figure 27, also from B14 to see the relationship.

As we have seen in other variables, the panhandle regions often differ from the general pattern. The three western-most subbasins on the North Canadian River (B11, B12, B13) and the two western-most on the North Fork of the Red River (B21, B22) show a distinct bimodal pattern in stream contents. The first peak is in late May, where all the subbasins have a peak. For the North Fork of the Red the second peak is in early April. This early peak is supported by a runoff maxima. However, the second peak for the North Canadian is in late June; there is not an associated runoff maxima at this time. There are several possible explanations for this apparently unsupported stream contents maxima. It could be a reflection of upstream (i.e., westward) precipitation and runoff exterior to the basins studied. The more probable explanation is that it is a limitation in the hydrologic accounting model. In the Oklahoma panhandle, where there is little native vegetation to retard runoff, heavier summer thunderstorms may result in runoff even though the model does not indicate it (see Section 4.4.3). In both cases, however, this bimodal pattern, which is not reinforced by

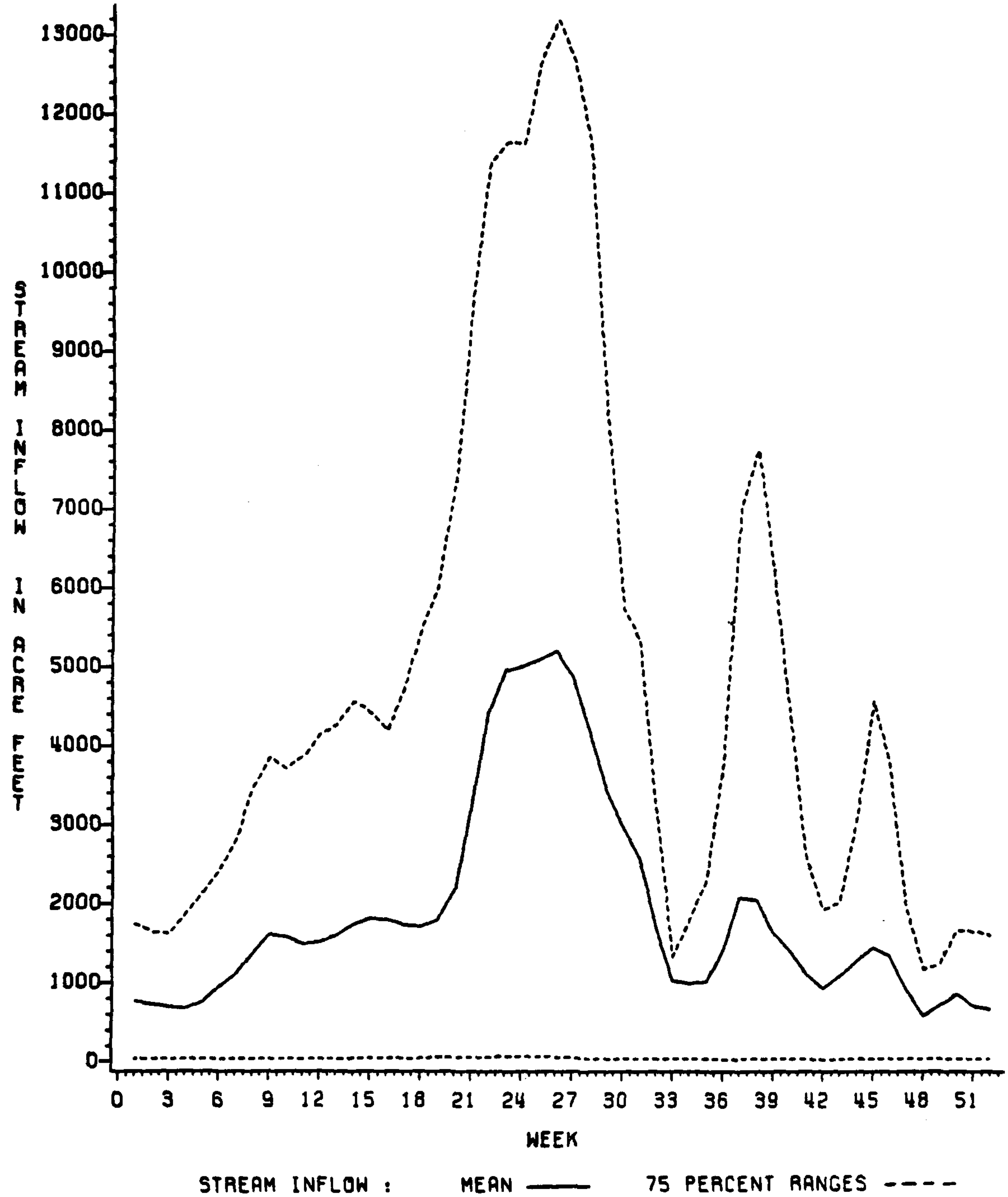

Figure 33. Stream inflow vs. time; long-term weekly means and 75 percent ranges for subbasin B14 of the North Canadian River; stream inflow in acre feet per week.

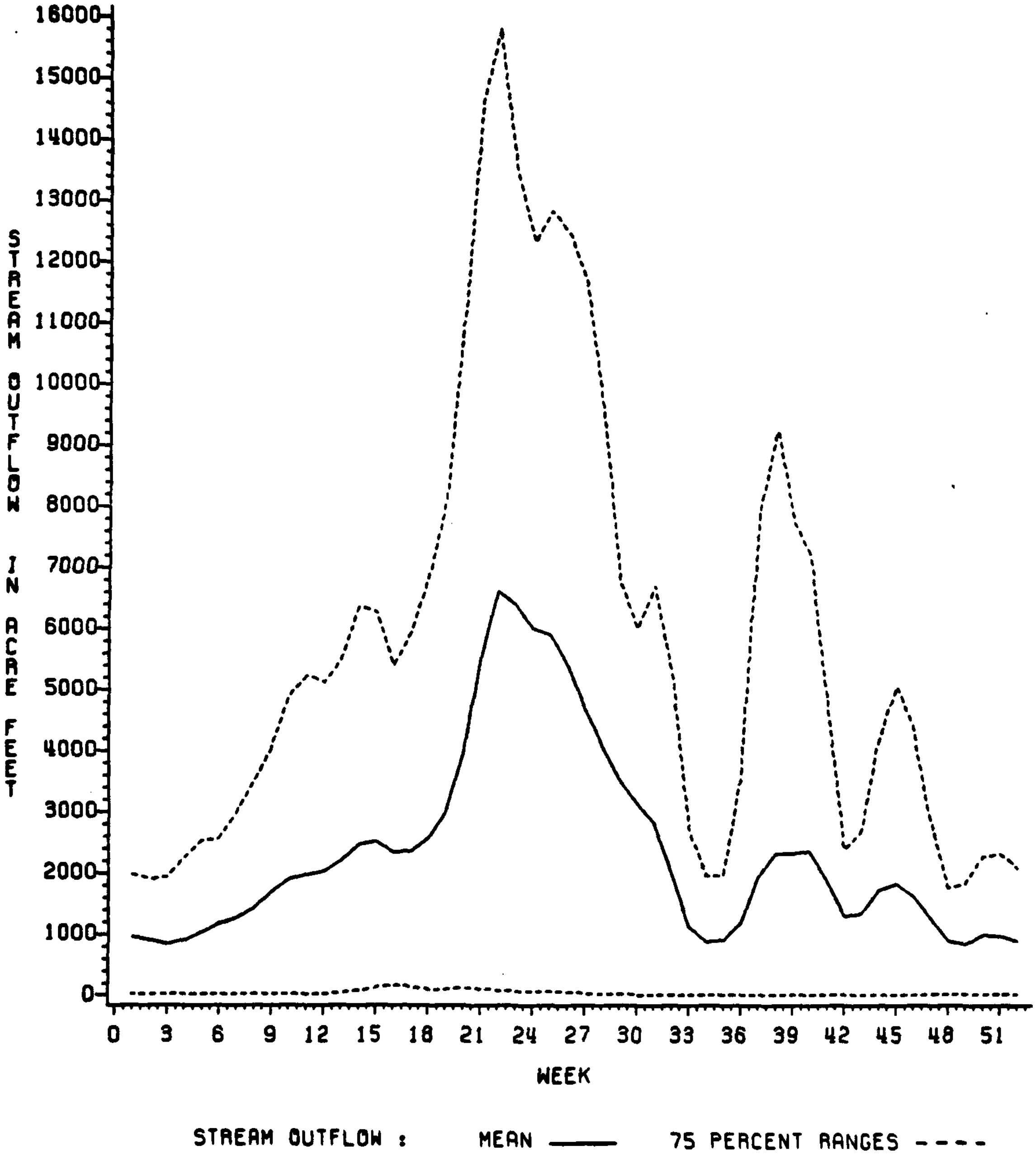

Figure 34. Stream outflow vs. time; long-term weekly means and 75 percent ranges for subbasin B14 of the North Canadian River; stream outflow in acre feet per week.

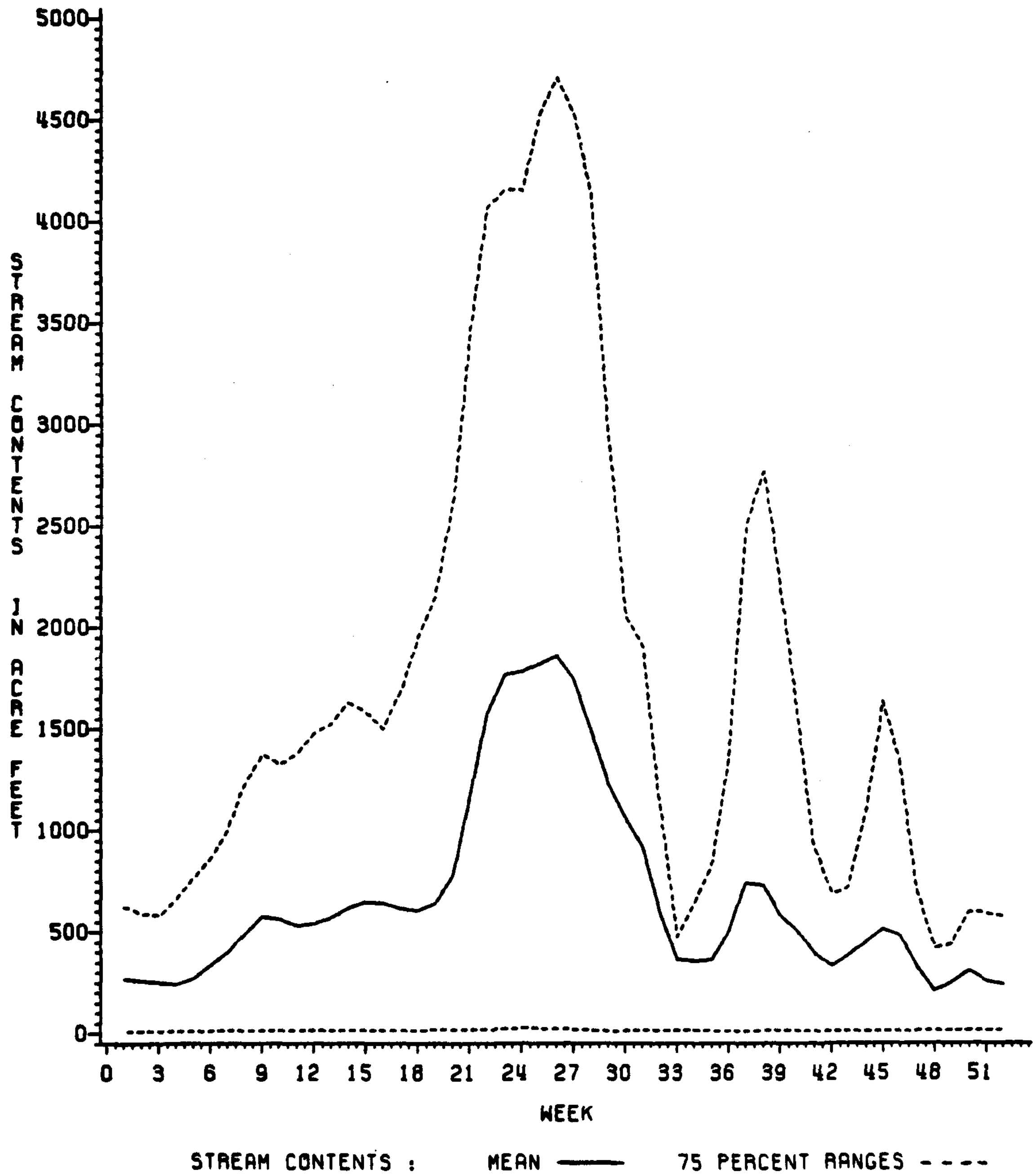

Figure 35. Stream contents vs. time; long-term weekly means and 75 percent ranges for subbasin B14 of the North Canadian River; stream contents in average acre feet per week.

a bimodal runoff pattern in the more eastern subbasins, becomes damped, emerging as the single late spring maximum discussed above.

A final factor that should be noted in stream inflow, outflow and contents is their order of magnitude (see Table 3). Stream contents is usually one order of magnitude less than either inflow or outflow. Once again, this is primarily a result of the computational assumptions (Section 4.2.3.5). Stream inflow and outflow are usually of the same magnitude, with outflow being larger. This is reversed in subbasins B13, B15 and B23, because of the presence of reservoirs in those subbasins. Stream inflow and outflow are usually the same or one order of magnitude less than runoff. Lastly, stream contents, which is a component of the storage Equation (4.7) is anywhere from two to five orders of magnitude less than the largest component, soil moisture.

5.2.6 Stream Evaporation Term

The calculation of the stream evaporation term was discussed in Section 4.2.3.6. Remembering that it is basically the difference between potential and actual evapotranspiration over the stream bed and surroundings, the characteristic curve is what we would expect. The curves are very similar from subbasin to subbasin, as were those for evapotranspiration and potential evapotranspiration. There is a rapid increase in the late spring (as evapotranspiration begins to decrease) to a maximum about the first of August (when potential evapotranspiration reaches its peak). Then it declines almost as rapidly as it increased. This stream evaporation term varies from equal magnitude with stream inflow or outflow to as much as five times as large, with

greater orders of magnitude in relation to stream contents in the panhandle regions. The stream evaporation term, then, negates any contribution that stream contents makes to the storage Equation (4.5). Figure 36 is representative of the stream evaporation term in the study basins.

5.2.7 Lake Contents and Lake Evaporation

Reservoirs, when they are present in a subbasin, provide a contribution to the storage equation of equal magnitude to that of soil moisture. Whereas in the mean, the soil moisture varies by at least one hundred percent through the course of the year, lake contents is much more conservative, varying only about twenty percent. Figure 37, for Canton Lake in subbasin B13, illustrates this. Note that the contents for Canton Lake are 15-year means and ranges, not 30-year means. Although Canton existed from 1951-1965, data were not available for that period. Due to the precipitation variability (see Figure 3), the 15-year mean should be considered only an approximation for the 30-years, 1951-1980.

Lake evaporation is two orders of magnitude smaller than lake contents at any time. The three lake evaporation curves have the identical shape, and no ranges, because of the way they were estimated (Section 4.2.3.4). Figure 38 is the lake evaporation for Canton Lake.

5.2.8 Channel Loss

Caution must be exercised when interpretating the channel loss term and inputing physical significance. The possible sources of error in channel loss were discussed in Section 4.3.2, where it was also

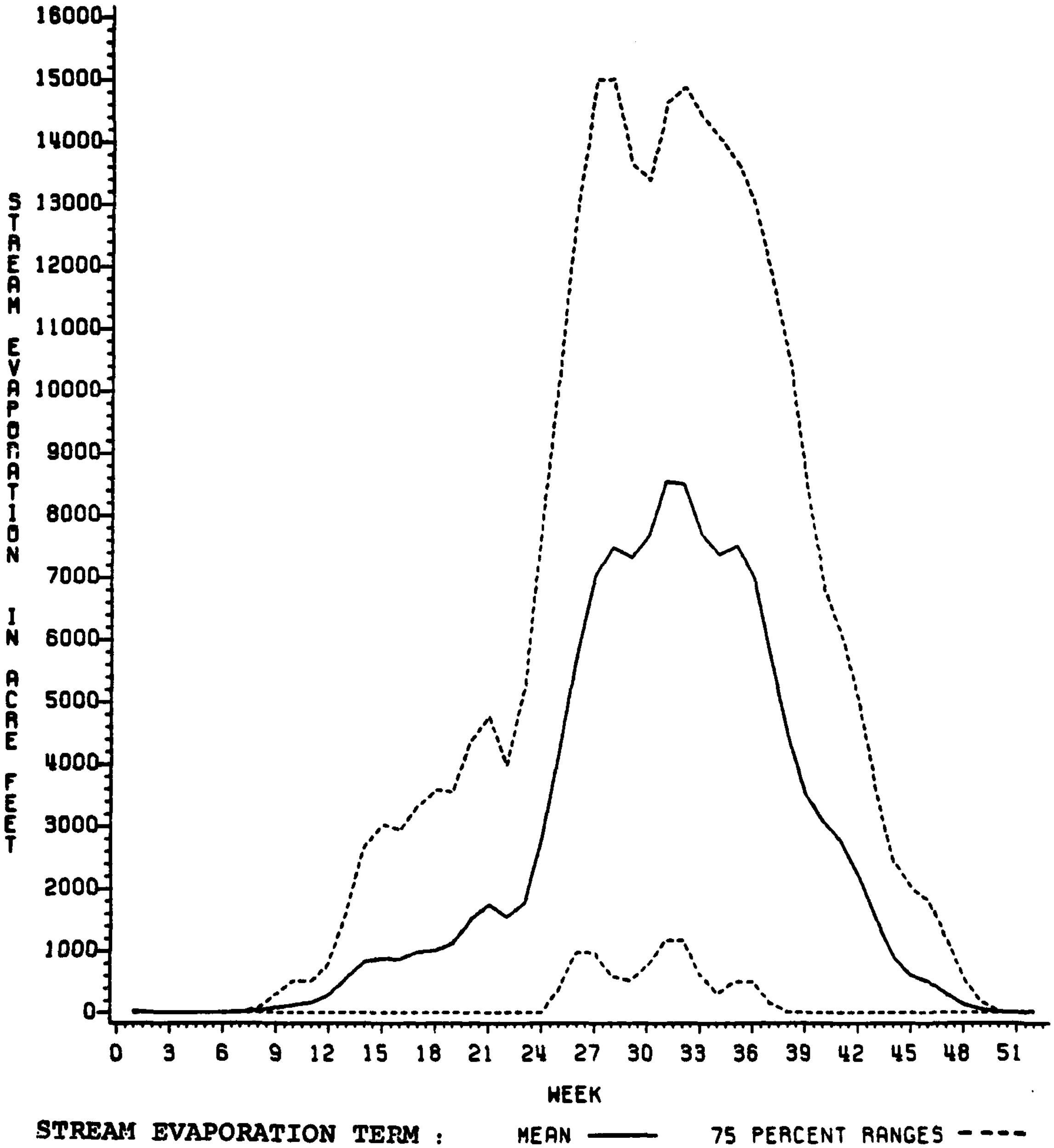

Figure 36. Stream evaporation term vs. time; long-term weekly means and 75 percent ranges for subbasin B12 of the North Canadian River; stream evaporation term in acre feet per week.

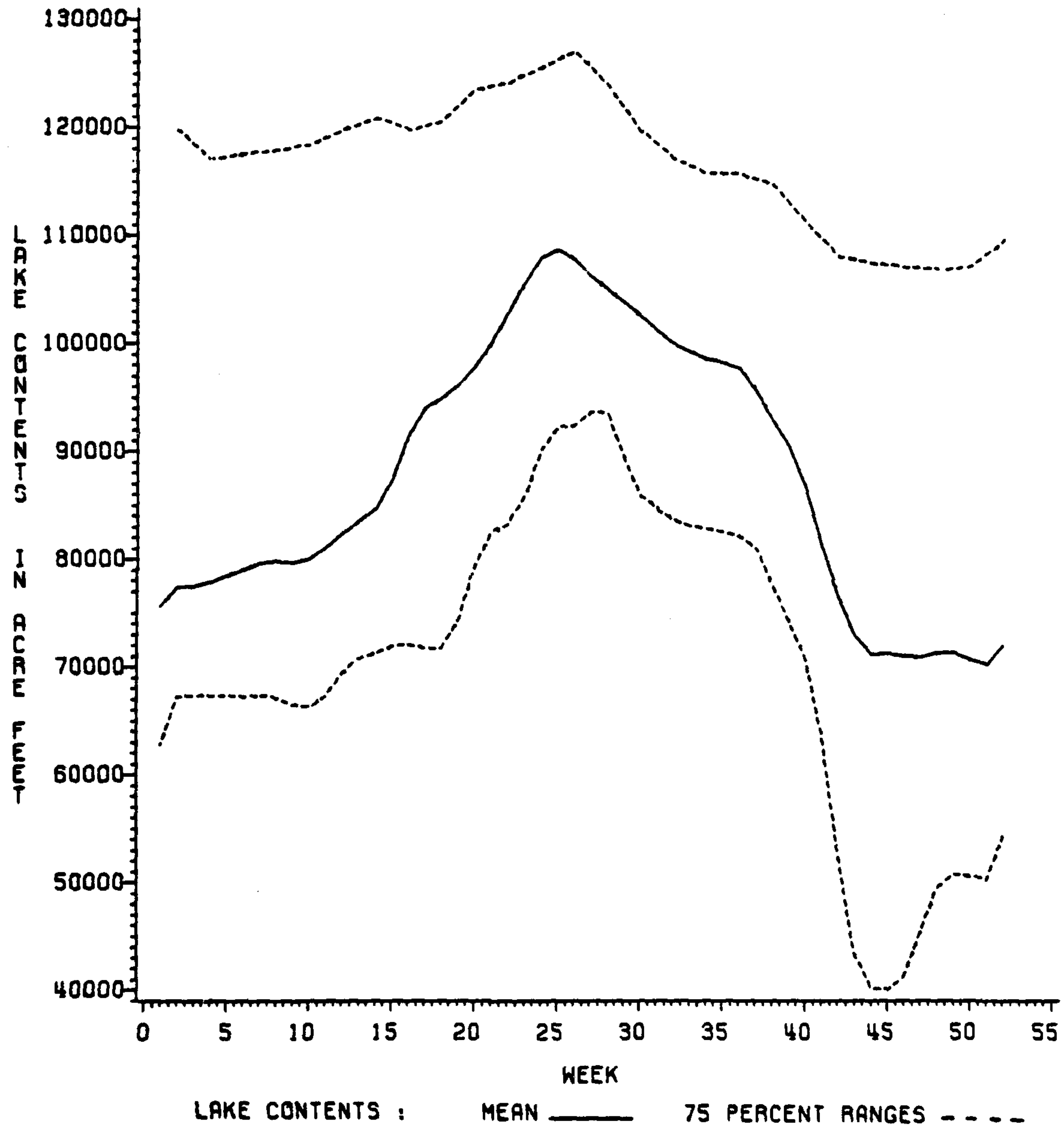

Figure 37. Lake contents vs. time; long-term weekly means and 75 percent ranges for subbasin B13 of the North Canadian River; note means are 15-year values; contents in average acre feet per week.

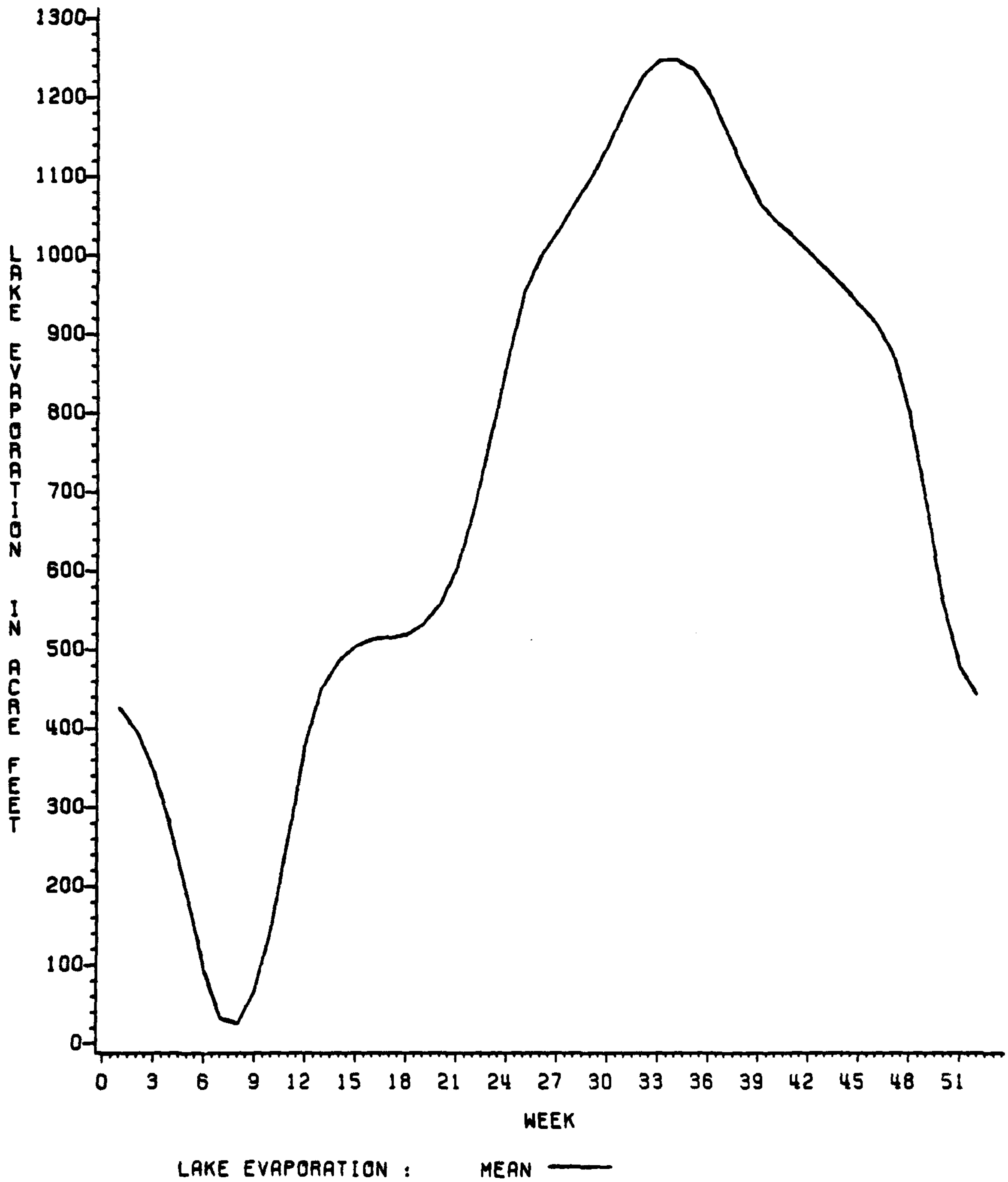

Figure 38. Lake evaporation vs. time; long-term weekly means for subbasin B13 of the North Canadian River; evaporation in acre feet per week.

emphasized that among other things, it plays the role of a balancing term. As such, a portion of its variability is due to errors in all other terms.

Channel loss exhibits the widest variability from subbasin to subbasin of any of the basic variables. However, two distinct parts of the channel loss term can be identified in all cases. The two primary components of channel loss (Equation 4.6) appear to be runoff and stream evaporation. The change in lake contents is small and the stream inflow and outflow appear largely to offset one another.

In the spring, channel loss is positive; that is, there is a loss from the stream channel into the surrounding alluvium and aquifers. The single or double peaks observed in the spring correspond to the runoff patterns in each subbasin. A double spring peak in the western subbasins (Figure 39), gradually becomes a single late spring peak farther east (Figure 40). As the effect of runoff wanes in early summer, the channel loss term becomes negative (i.e., channel gain), meaning the stream channel must gain water from surrounding aquifers if balance is to be maintained. This occurs as the stream evaporation term begins to increase rapidly in size. In the late summer, when stream evaporation has decreased in magnitude, the effect of runoff again becomes apparent. The large channel gain in Figure 39 appears in most of the farther western subbasins.

The presence of a reservoir in a subbasin produces a channel loss pattern with a much smaller negative (gain) component (see Appendix C). In fact, in two of the three subbasins containing reservoirs (B15, B23) the 30-year means for channel loss never become negative.

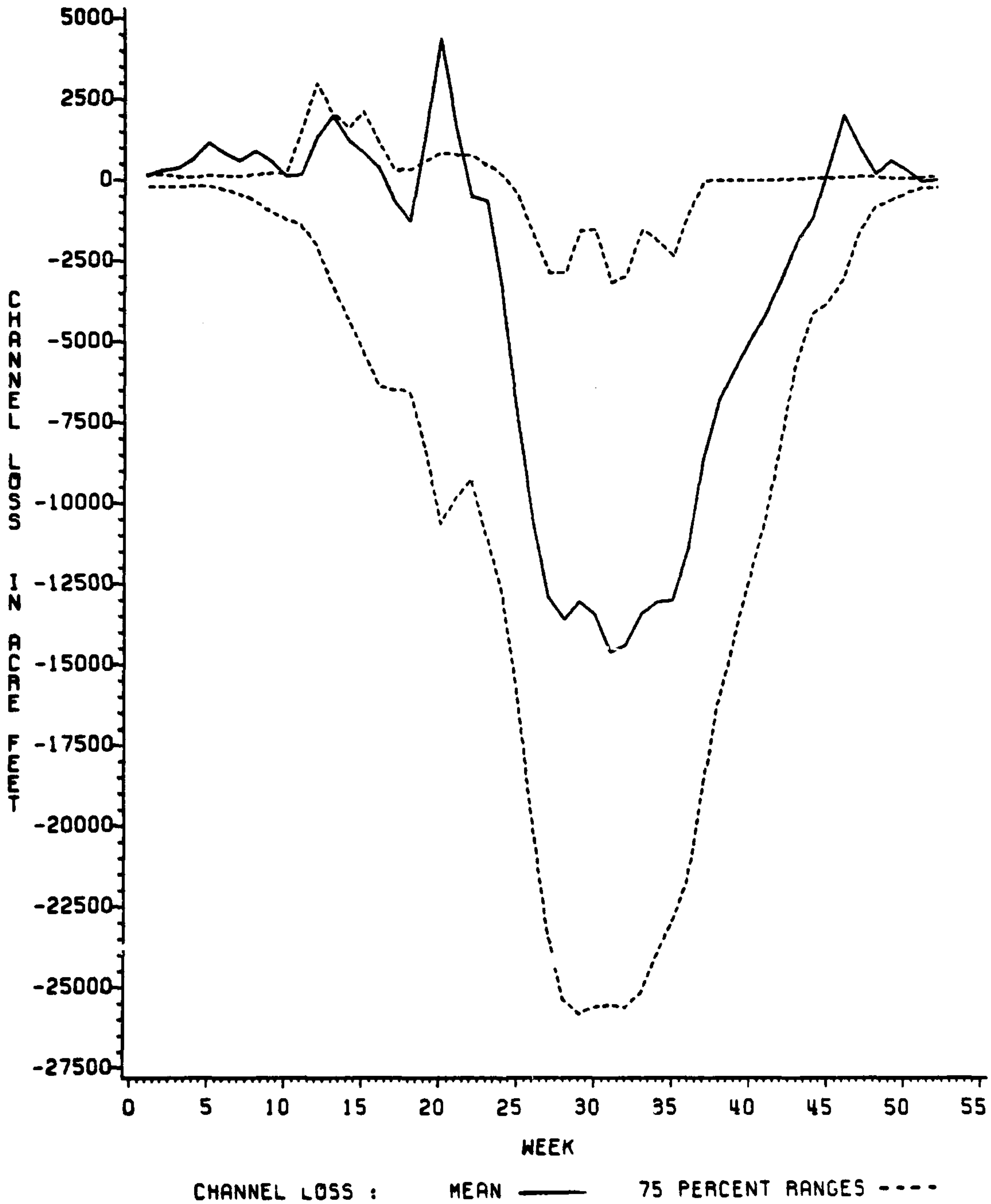

Figure 39. Channel loss vs. time; long-term weekly means and 75 percent ranges for subbasin B21 of the North Fork of the Red River; channel loss in acre feet per week.

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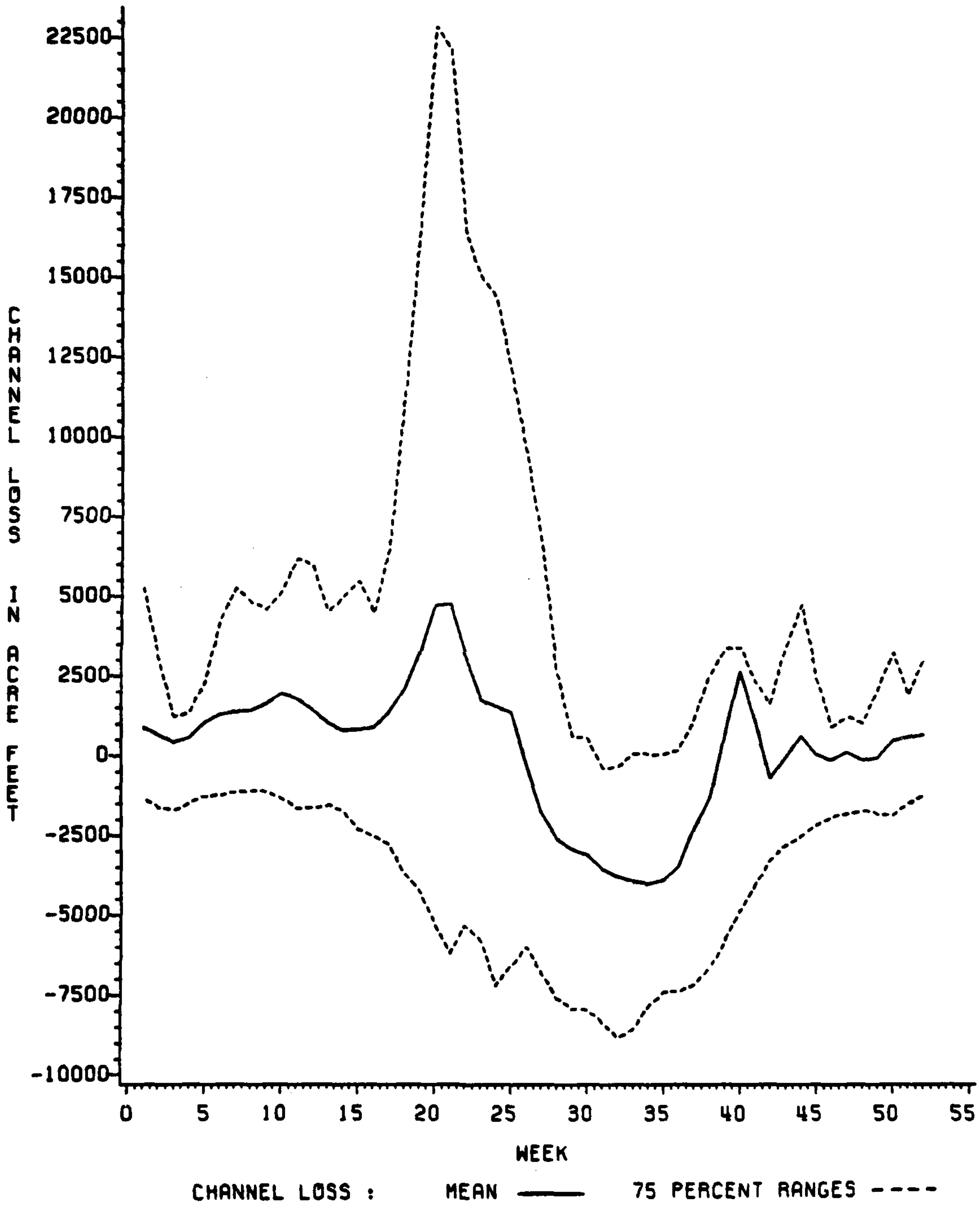

Figure 40. Channel loss vs. time; long-term weekly means and 75 percent ranges for subbasin B16 of the North Canadian River; channel loss in acre feet per week.

The ameleorating affect of a reservoir is probably due to controlled releases in the summer for either municipal and industrial or agricultural uses.

5.3 Delta

Delta is the direct contribution of precipitation toward satisfying evapotranspiration demands. Its derivation and physical description were discussed briefly in Section 4.4.3 and it was calculated from Equation (4.11), which is

$$\text{Delta} = P - R - RO ,$$

where P is precipitation, R is soil moisture recharge and RO is runoff. In this section we discuss the typical yearly pattern of delta and several of its implications, using examples from subbasin B12.

Figure 41 shows long-term weekly means for actual (ET) and potential (PET) evapotranspiration, and delta. The characteristics of ET and PET were discussed in Section 5.2.4. In Figure 41 we see the PET peak in mid-July (week 28), the ET peak in mid-June (week 24) and the largest delta peak in early June (week 22). Prior to week 22 the increase in ET closely followed PET, indicating there was no shortage of moisture. In week 22 ET (33,000 AF) is less than fifteen percent below PET (38,000 AF) and delta (23,000 AF) supplies seventy percent of the ET requirement. Figure 42 shows that the mean peak storage (defined in Equation (4.7)) is 175,000 AF, or five times larger than ET.

After week 22 precipitation rapidly decreases and within two weeks ET has peaked and begun to decrease. In just five weeks (by week 27) ET (which has the same value as in week 22) is only sixty percent

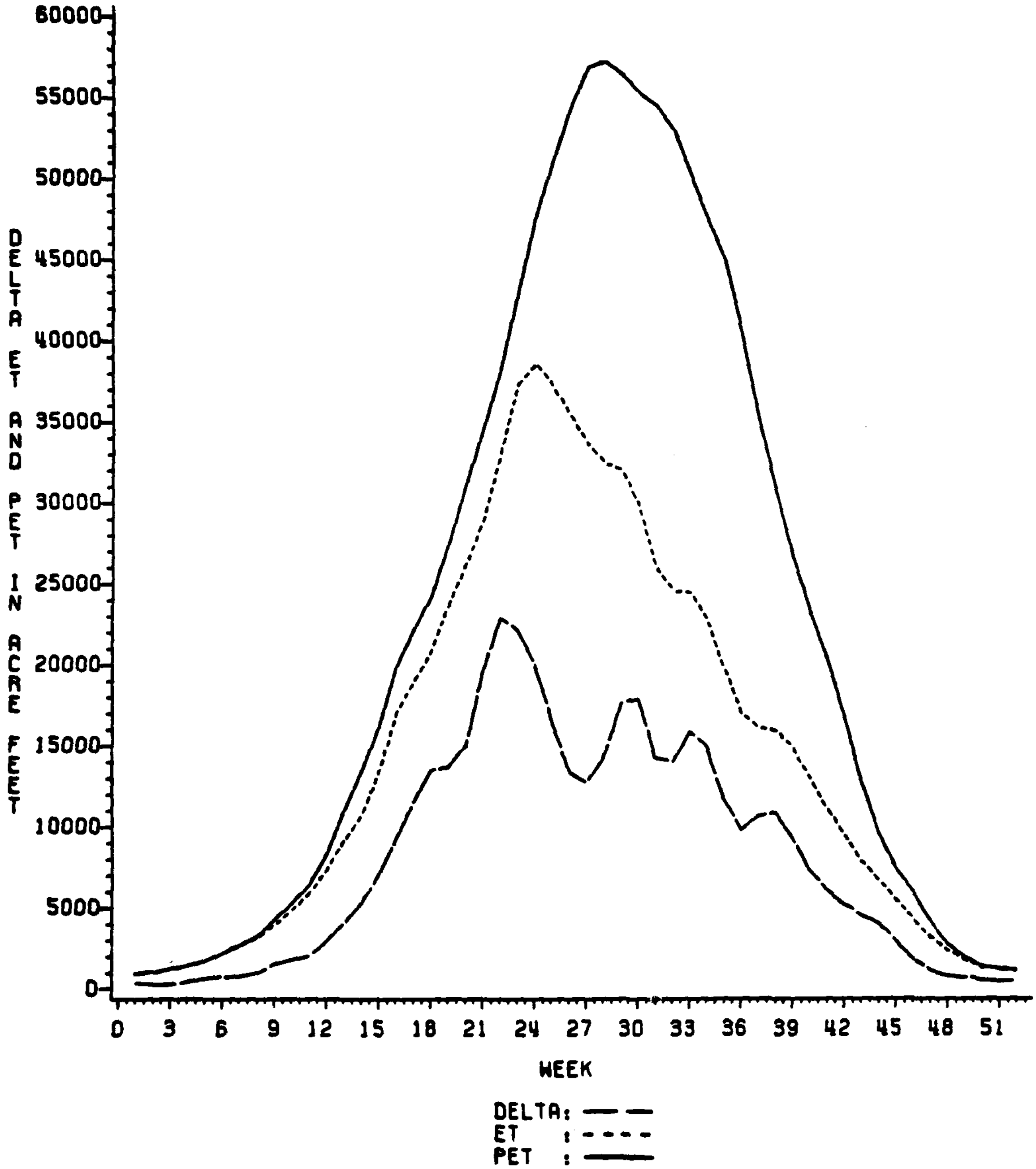

Figure 41. Delta, potential (PET) and actual (ET) evapotranspiration vs. time; long-term means for subbasin B12 of the North Canadian River; delta, ET and PET in acre feet per week.

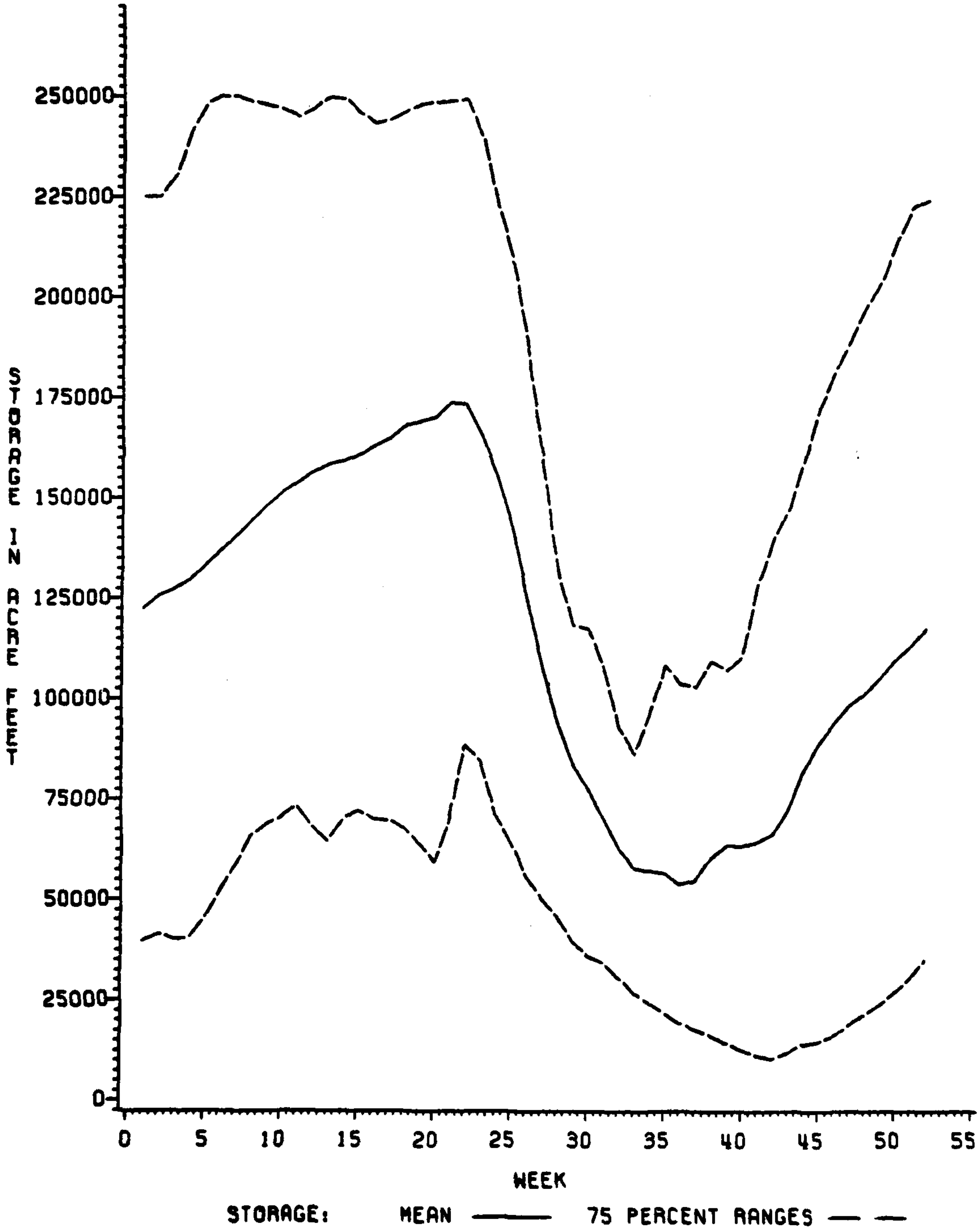

Figure 42. Storage vs. time; long-term weekly means and 75 percent ranges for subbasin B12 of the North Canadian River ; soil moisture in average acre feet per week.

of PET, and precipitation now supplies less than forty percent of ET demands. The remaining ET is satisfied by storage (i.e., soil moisture). As a consequence, soil moisture decreases by over a third (175,000 to 110,000 AF) in only five weeks! In the next seven weeks (roughly July and August) storage will continue to decrease, to less than a third of its value in early June (55,000 AF), as it gives up moisture to ET demands.

Figure 43 shows the variables used to calculate delta; precipitation, soil moisture recharge and runoff. The precipitation and runoff have been discussed previously, but in this presentation we can see easily why late summer precipitation does not produce significant runoff. After evapotranspiration demands of growing vegetation are satisfied, the remaining precipitation is used largely for soil moisture recharge.

In most cases runoff is less than soil moisture recharge, and in all cases precipitation is, of course, greater than either. However, in the two eastern-most subbasins on the North Canadian (B15, B16) the rainfall is heavy enough to cause runoff to excede recharge in the late spring. For example, see Figure 44.

Figure 41 demonstrates a further piece of information. If we define evapotranspiration as a measure of crop growth potential (Major, 1965) we see that moisture constrains growth from late May through September (weeks 22 to 39). This "emphasizes the fact that the greater part of the dryland crops' growth during this period is dependent directly on precipitation (Eddy, 1982).

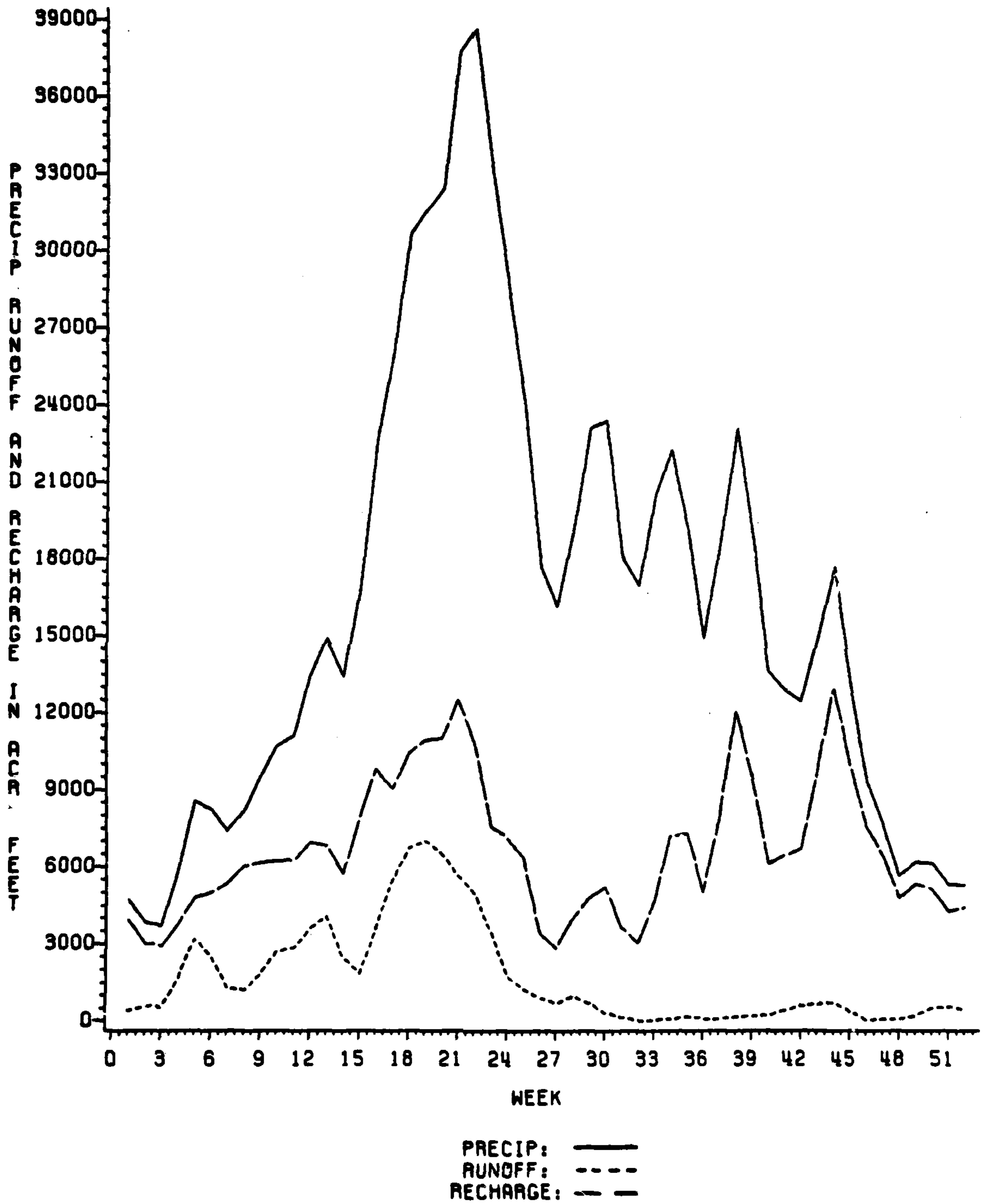

Figure 43. Precipitation, recharge and runoff vs. time; long-term weekly means for subbasin B12 of the North Canadian River; precipitation, runoff and recharge in acre feet per week.

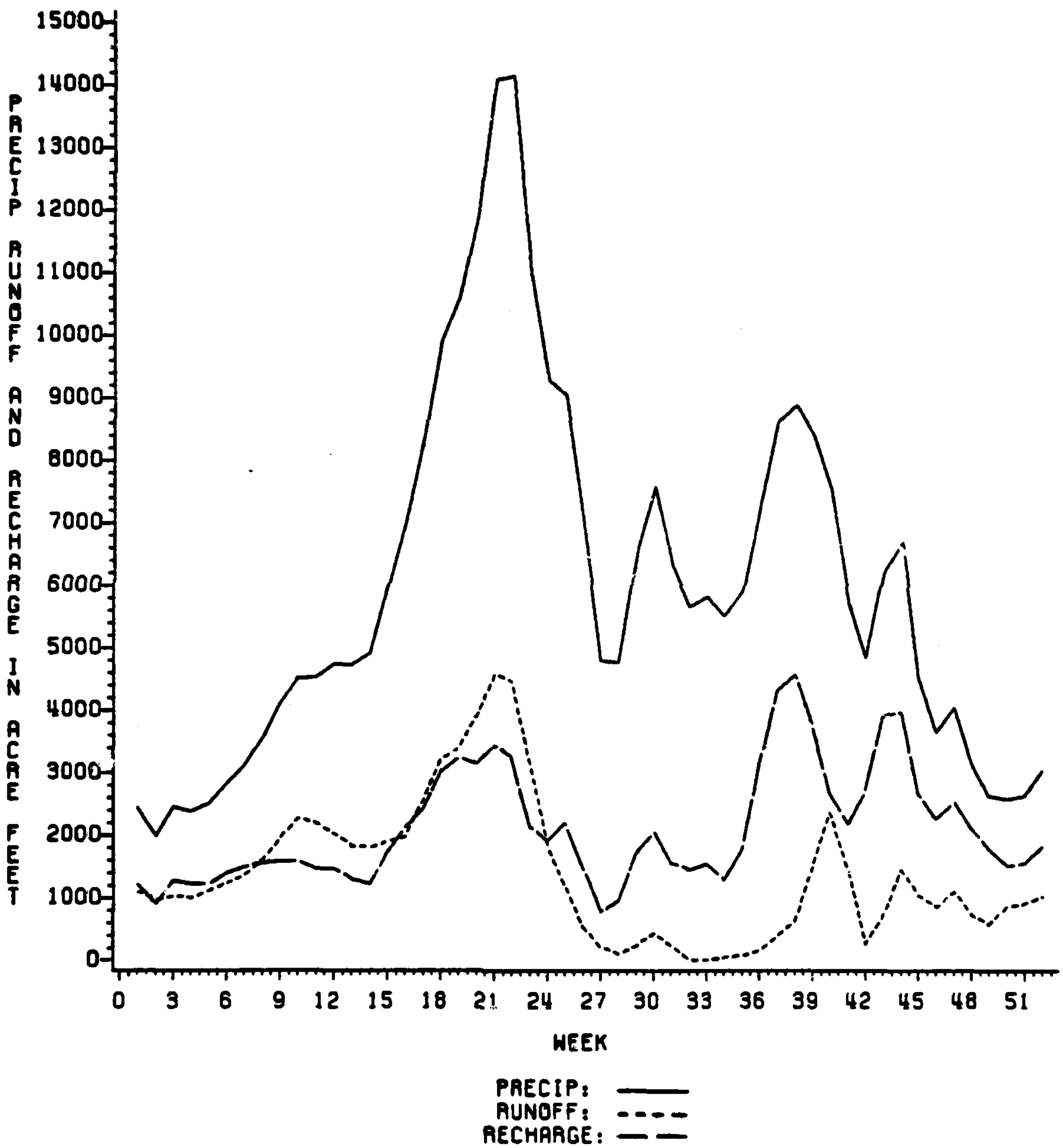

Figure 44. Precipitation, recharge and runoff vs. time; long-term weekly means for subbasin B15 of the North Canadian River, precipitation, runoff and recharge in acre feet per week.

5.4 Storage and Demand

By examining the relationship between the storage and demand curves we can address the crux of this thesis; namely: the time during the year when water deficits occur and the frequency with which they can be expected. In Section 4.4.2 the derivation of storage and demand was discussed. We recall that Equation (4.7) defined storage as

$$S = SM + LC + CC$$

and Equation (4.8) defined demand as

$$D = ET + SE + LE + CL \ .$$

We also recall that the principal components of storage are soil moisture and lake contents, while demand is mainly evapotranspiration. Consequently, the demand curve and the evapotranspiration curve are very similar. Compare Figure 32 (ET) with Figure 45 (demand), both for subbasin B13. Conversely, storage and soil moisture curves are essentially the same, if there is not a lake in the subbasin. Compare Figure 29 (soil moisture) and Figure 46 (storage), both for subbasin B14.

When a subbasin contains a reservoir the wide variation normally found in storage (primarily the dramatic early summer drop) is damped out (a result which is, of course, part of the purpose of the reservoir). Compare Figure 46 with Figure 47, which is from the adjacent upstream subbasin. The decrease in storage variability is readily apparent.

If we plot the long-term weekly mean values and 75 percent empirical envelopes for storage and demand on the same graph their relationship becomes clearer. For example, Figure 48 is storage and

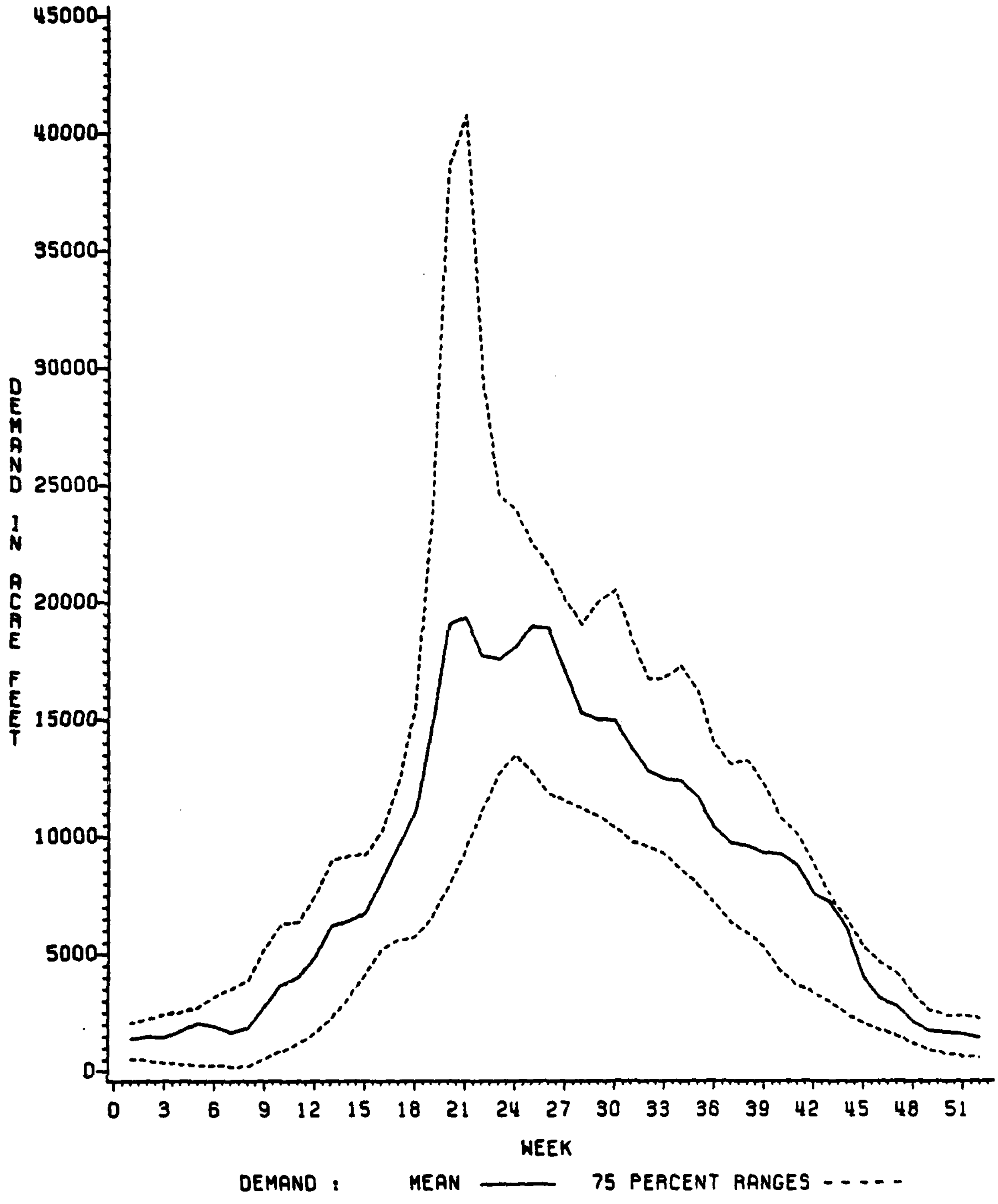

Figure 45. Demand vs. time; long-term weekly means and 75 percent ranges for subbasin B13 of the North Canadian River; demand in acre feet per week.

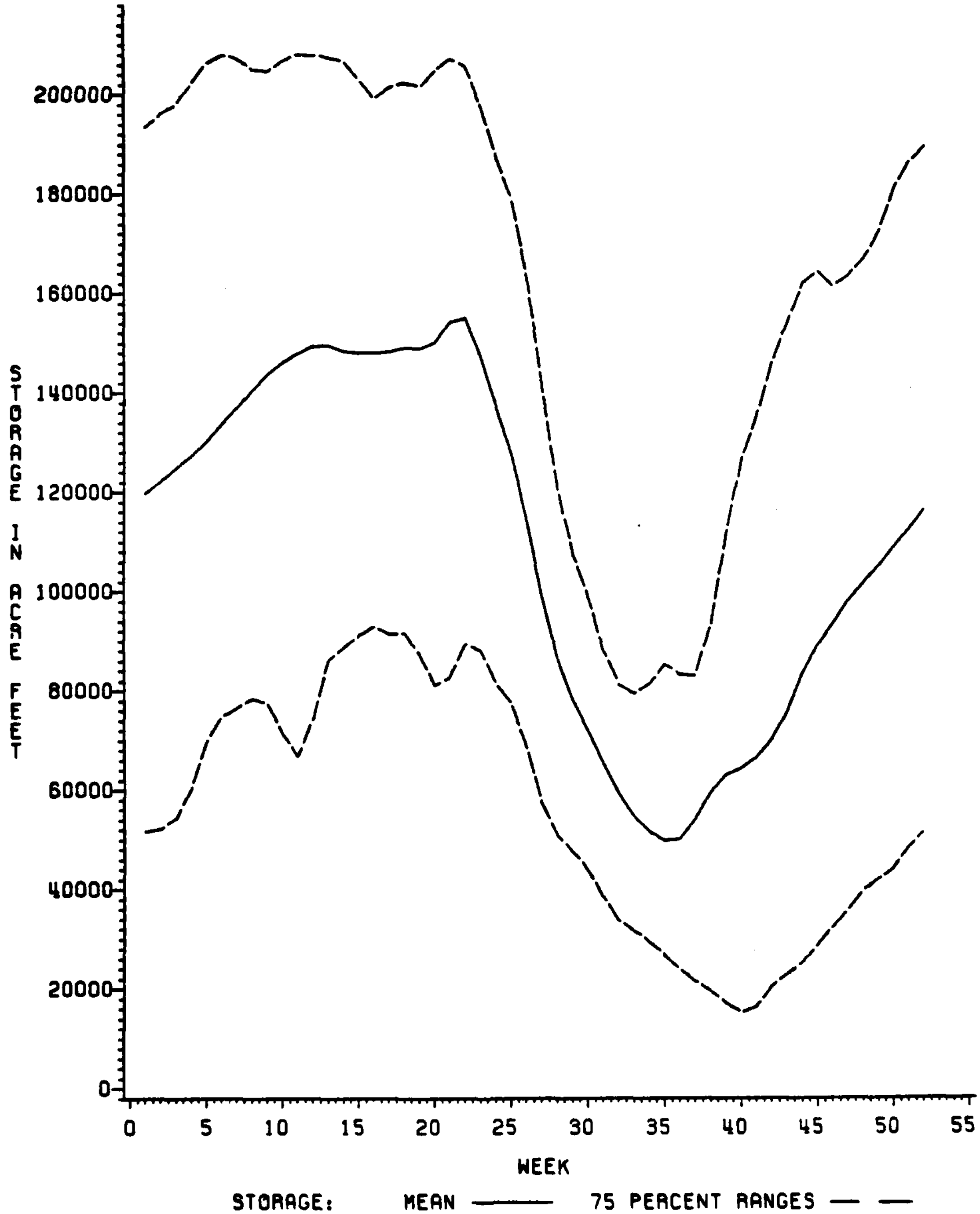

Figure 46. Storage vs. time; long-term weekly means and 75 percent ranges for subbasin B14 of the North Canadian River; storage in average acre feet per week.

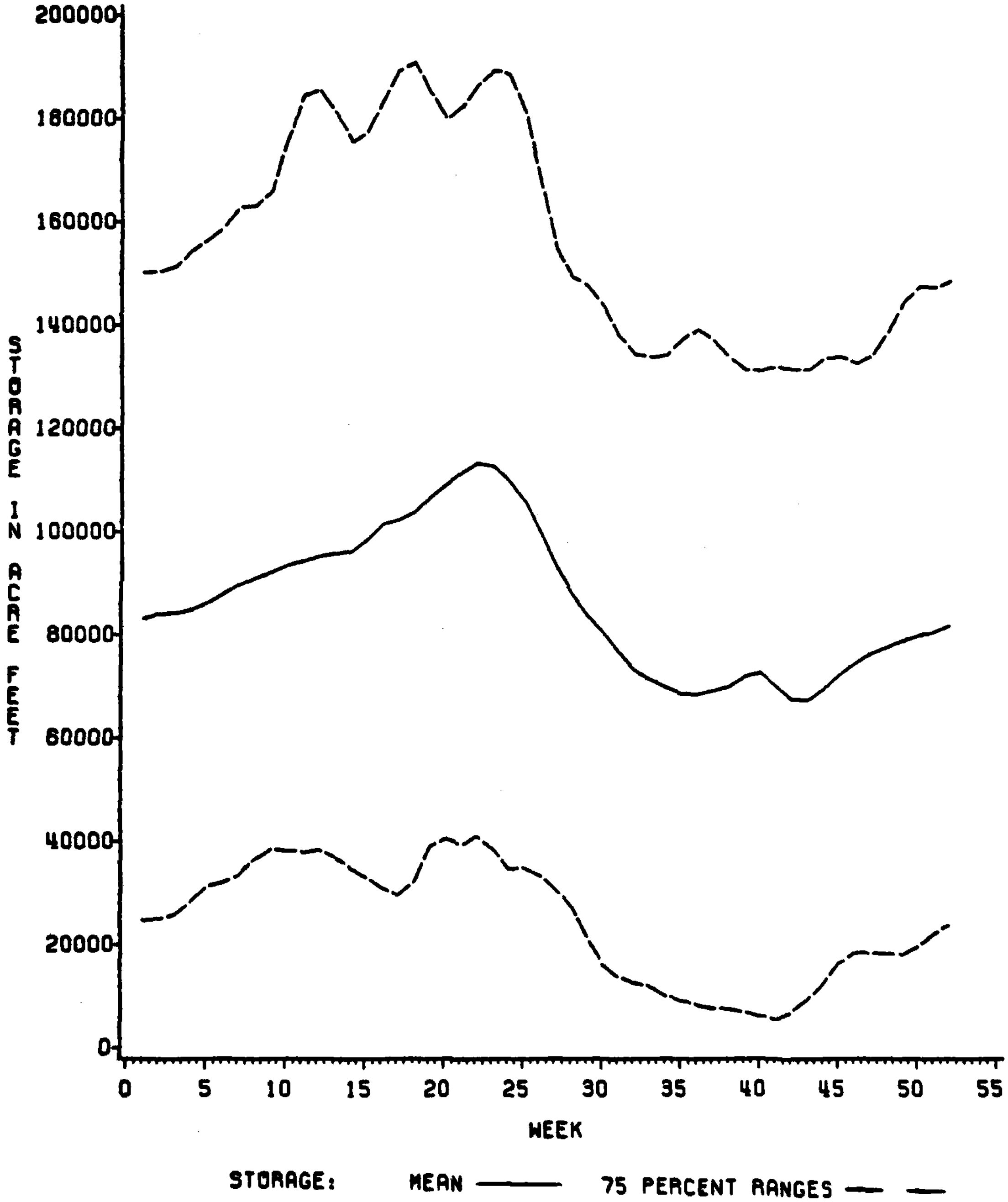

Figure 47. Storage vs. time; long-term weekly means and 75 percent ranges for subbasin B13 of the North Canadian River; storage in average acre feet per week.

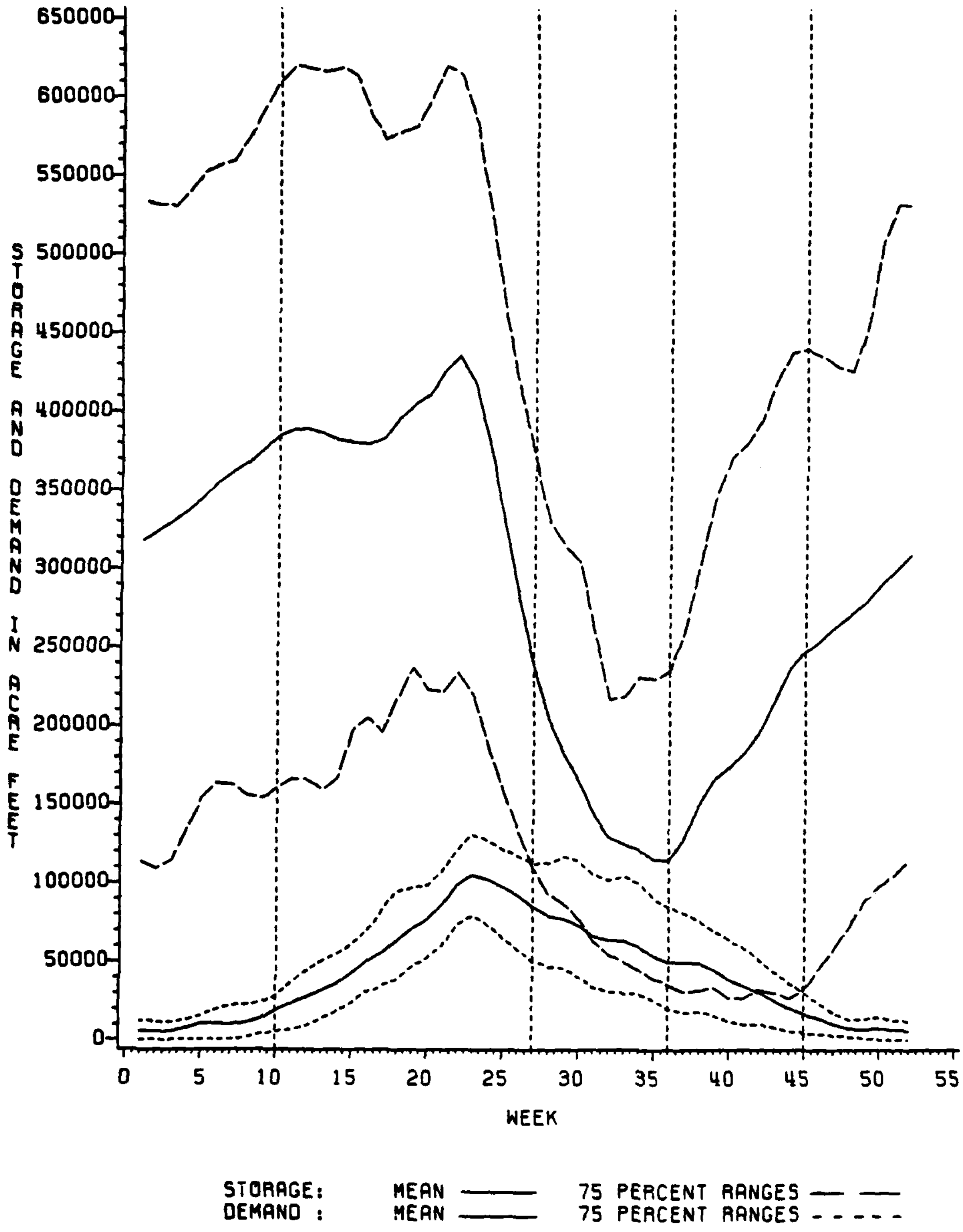

Figure 48. Storage and demand vs. time; long-term weekly means and 75 percent ranges for subbasin B24 of the North Fork of the Red River; storage and demand in acre feet per week.

demand for subbasin B24, which is immediately downstream from Altus Lake. The dashed vertical lines highlight times of interest, or critical periods, during the year. We can define a potential deficit as whenever the 75 percent empirical envelopes for storage and demand intersect. The first dashed vertical line marks the middle of the excess period (i.e., the period in which the storage and demand envelopes do not intersect). This occurs in early March (week 10). The remaining three dashed vertical lines mark the beginning, middle and end of the deficit period (i.e., the period when the storage and demand envelopes have a portion in common).

There are two points to note when comparing critical periods from subbasin to subbasin. First, there is considerable variability in time of occurrence for the middle of the excess period, and the beginning of the deficit period. The average mid-excess point is week 10 (mid-March) but values vary from week 6 (mid-February) to week 16 (late April). The average beginning of the deficit period is week 26 (late June), but it ranges from week 17 to week 32 (late April to mid-August). The beginning of the deficit period occurs, in most cases, later in the year as you progress eastward.

The second point to note is that the middle and end of the deficit period do not vary much from subbasin to subbasin. The average mid-deficit time is week 35 (first of September); the range is week 32 to week 38 (mid-August to mid-September). The uniformity of the end of the deficit period is more striking, with an average of week 44 (early November) and a range of week 42 to week 46 (late October to late November). The average duration of the deficit period is eighteen

weeks and ranges from twelve to twenty-nine weeks (except in B15, where it is only two weeks long). Table 4 summarizes the critical week values by subbasin.

At this point it is important to emphasize what the beginning and ending of the deficit period mean. At these times, when the empirical 75 percent envelopes for storage and demand intersect, about twelve percent of the storage values are less than the intersection value and twelve percent of the demand values are greater. That does not mean that in any given year demand is greater than storage. It may be, but it is not necessarily so.

In the remainder of this section we will examine the storage and demand pictures for subbasins B11 and B23 and quantify the frequency of potential water deficits.

Table 4. Long-term mean values for critical weeks, by subbasin.

Subbasin	Mid-excess	Start deficit	Mid-deficit	End deficit
11	6	19	32	45
12	10	27	36	44
13	14	29	36	43
14	10	30	36	42
15	12	37	38	39
16	12	32	38	44
21	6	20	32	44
22	16	26	36	45
23	6	17	32	45
24	10	27	36	45
Mean (all Subbasins)	10	26	35	44

5.4.1 Subbasin B11 of the North Canadian River

Subbasin B11 is the western-most of the study basins, located in the Oklahoma and northern Texas panhandles. Figure 49 is the combined storage and demand picture for B11. The deficit period lasts twenty-six weeks, or eight weeks longer than the study area average. It begins seven weeks earlier than the average and ends one week later. In week 30, just prior to the middle of the deficit period, we find about twelve percent of storage values are less than almost eighty-eight percent of the demand values. Percentage frequency histograms for weeks 6 and 33 (mid-excess and mid-deficit periods) illustrate the change in storage and demand distributions. During week 6 (Figure 50) we observe that there is no overlap of storage and demand values. All the demand is 200,000 acre feet (AF) or less while storage values range from 400,000 AF to 3,800,000 AF. However, by week 32 (Figure 51) there is considerable overlap. For example, demand is 600,000 AF or greater in 40 percent of the years, while storage is 600,000 AF of greater in 68 percent of the years. Looking at the 400,000 AF level, we see demand excedes that value in 66 percent of the years; storage excedes it in 82 percent of the years. The histograms illustrate the long-term distributions of storage and demand for a particular week, but they do not reveal whether demand excedes storage in any given year.

A way to quantify how frequently storage and demand in a particular year will result in a problem (i.e., a deficit) is with a joint frequency distribution. Tables 5 and 6 show such distributions for the middle of the excess and deficit periods in B11. The interval values are non-uniform. They were defined using the mean value for storage

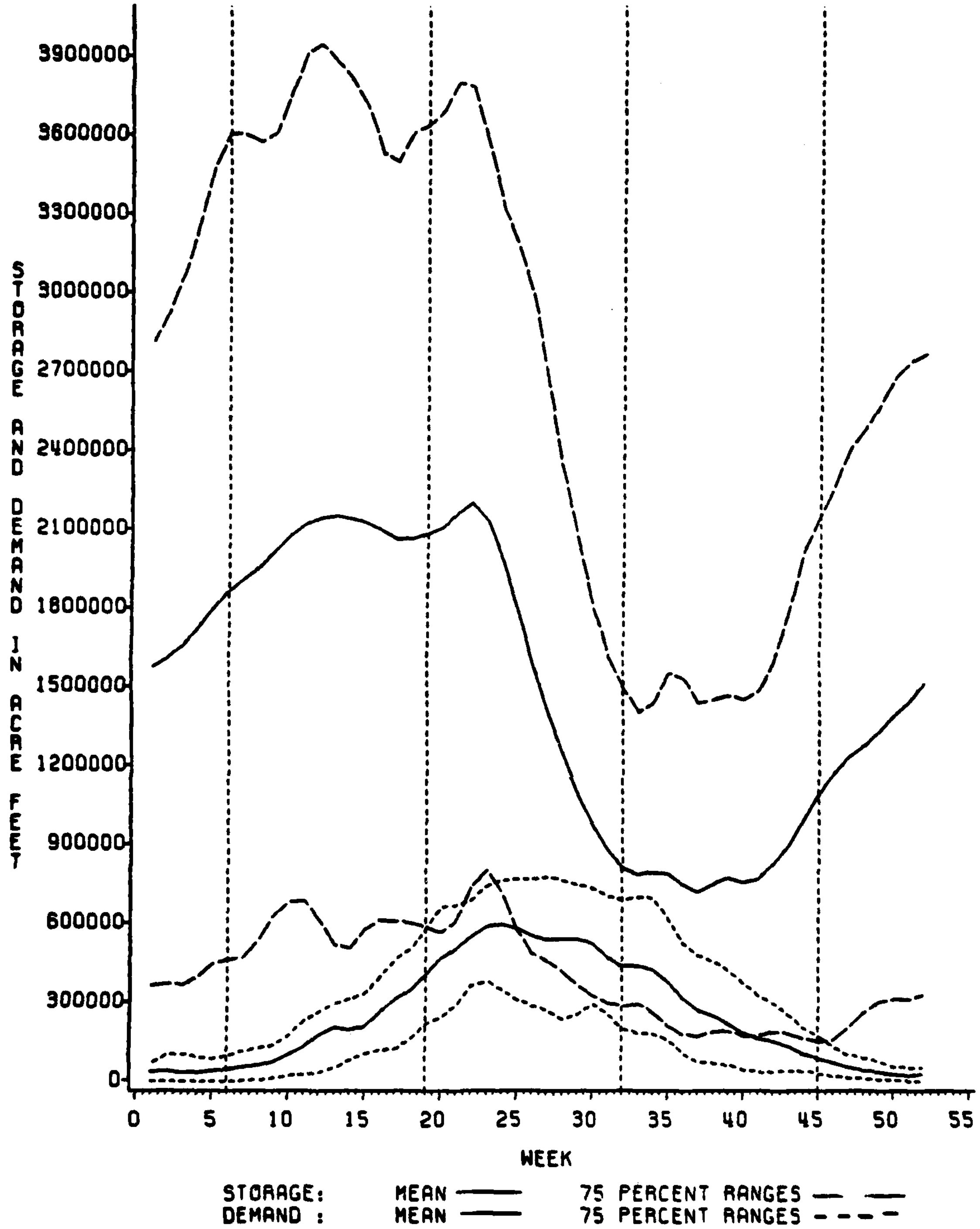

Figure 49. Storage and demand vs. time; long-term weekly means and 75 percent ranges for subbasin B11 of the North Canadian River; storage and demand in acre feet per week.

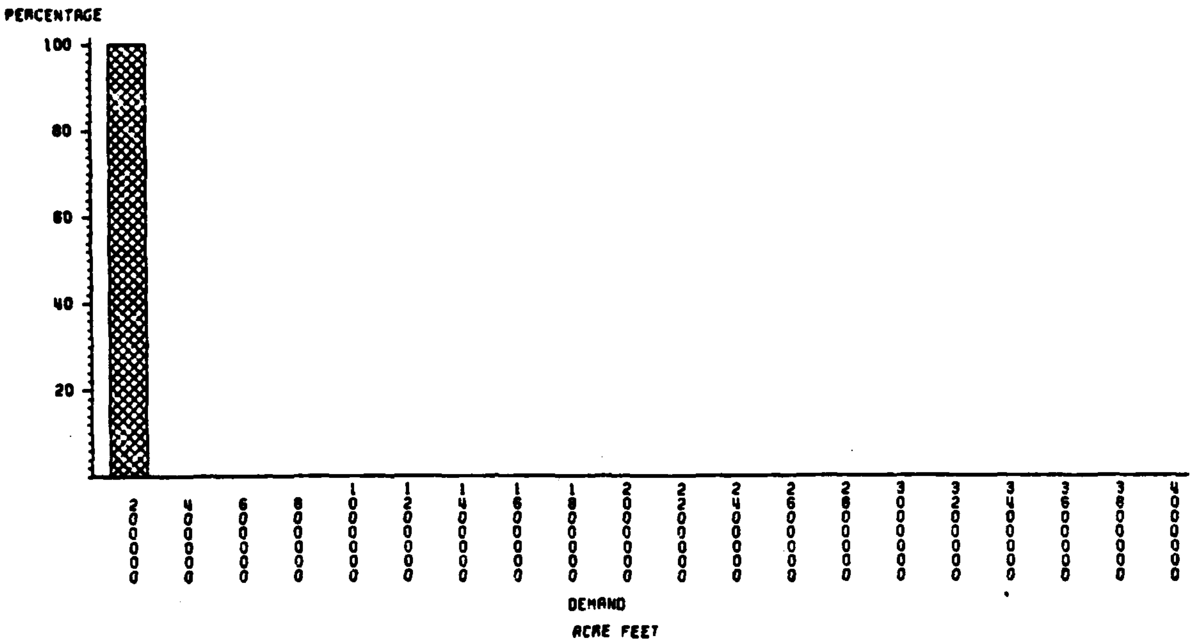

Figure 50a. Percentage frequency of demand for the middle of the excess period (week 6) for subbasin B11 of the North Canadian River.

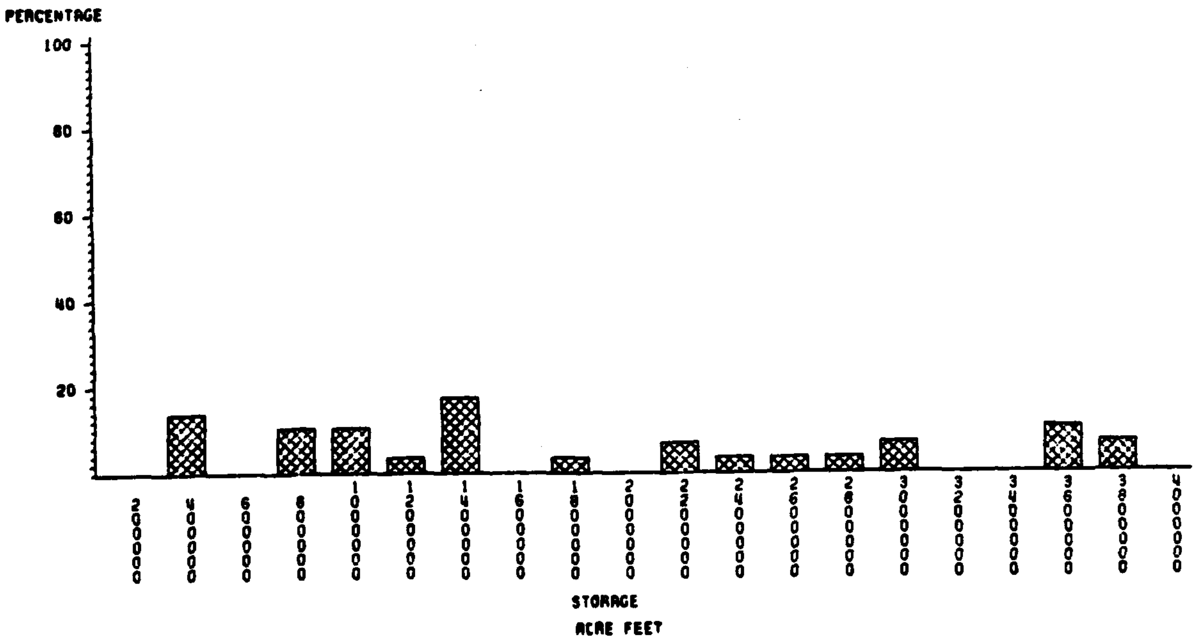

Figure 50b. Percentage frequency of storage for the middle of the excess period (week 6) for subbasin B11 of the North Canadian River.

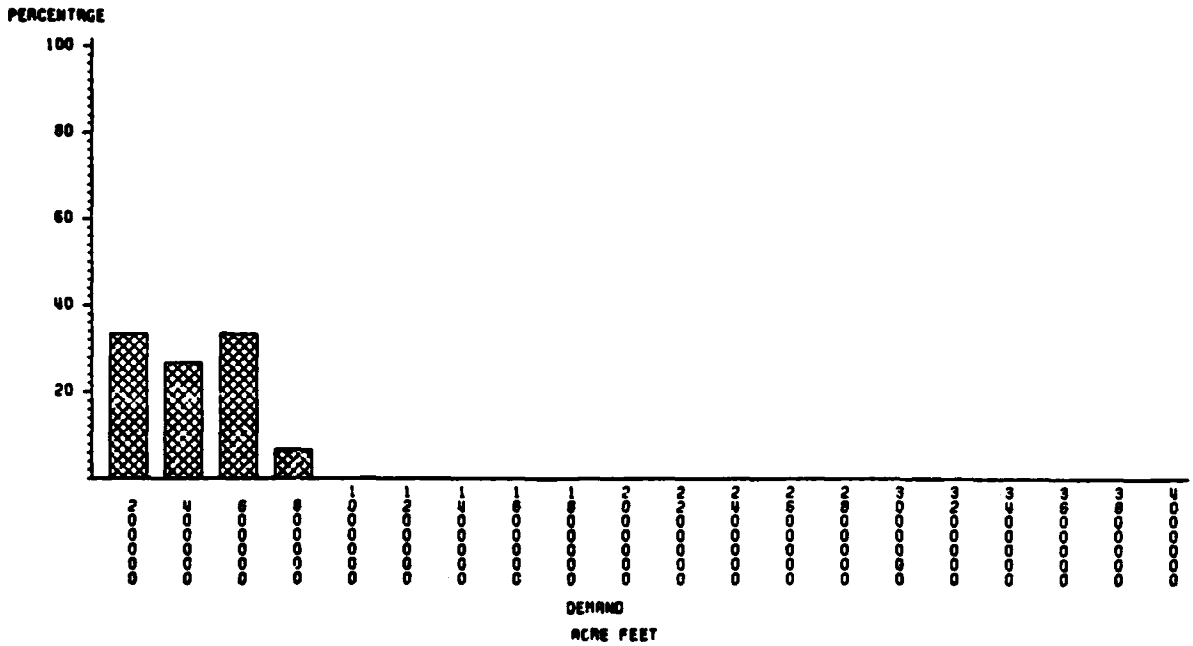

Figure 51a. Percentage frequency of demand for the middle of the deficit period (week 32) for subbasin B11 of the North Canadian River.

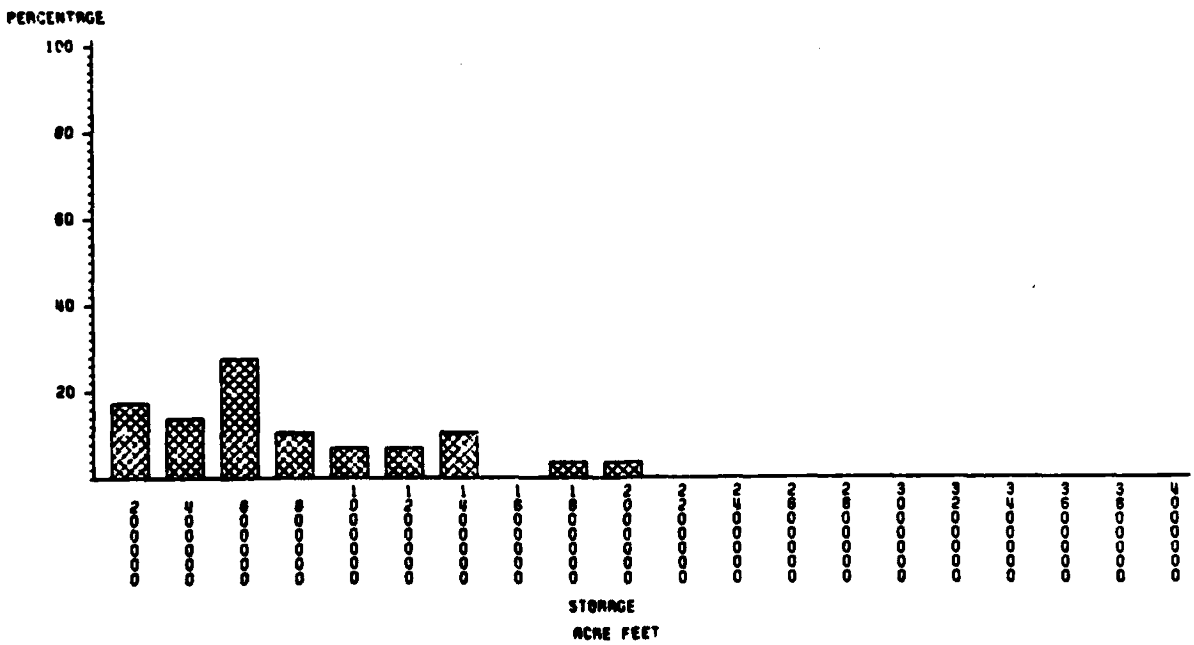

Figure 51b. Percentage frequency of storage for the middle of the deficit period (week 32) for subbasin B11 of the North Canadian River.

and the empirical 75 percent envelope endpoint values for both storage and demand. The values of most interest are those on or below the diagonal. In Table 5, six of the thirty years of record are on the diagonal, however, they are all in a large interval, 45,000 to 1,850,000 AF. Inspection of Figure 50 would lead us to believe there is little, if any overlap in storage and demand here. Table 6 is a different story. One third of the time (10 years in 30) we could expect water deficit problems, as demand requirements equal or excede storage.

5.4.2 Subbasin B23 of the North Fork

Subbasin B23, in southwestern Oklahoma, contains Altus Lake. Figure 52 shows the combined storage and demand picture. In the middle of the deficit period, twelve percent of the weekly storage values are lower than eighty-eight percent of the demand values. Figures 53 and 54 show the storage and demand distributions for the mid-excess and mid-deficit periods. Here we find some overlap even in the middle of the excess period, and considerable overlap by the middle of the deficit period. For example, in the mid-deficit period, demand is 15,000 AF or less in 83 percent of the years, while storage is 15,000 AF or less in 52 percent of the years. Again, this does not reveal in which years, if any, demand excedes storage. However, the joint frequency tables for these same weeks show that ten percent of the time water deficit problems could be expected to exist in the middle of the excess period (Table 7). However, Table 8 shows that almost half of the time (14 of 30 years) we can expect water deficit problems in the middle of the deficit period!

Table 5. Joint frequency table for subbasin B11, week 6 (mid-excess period).

0	0	0	5	2	0	5
0	0	0	1	0	1	1
0	0	0	5	2	2	5
0	0	0	6	4	2	6
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	17	8	5	30

DEMAND: 1, 10, 45, 1850, 3600

STORAGE: 1, 10, 45, 1850, 3600

Storage and demand in thousands of acre feet.

Table 6. Joint frequency table for subbasin B11, week 32 (mid-deficit period).

1	1	3	0	0	0	5
0	0	3	2	0	0	5
0	3	6	0	8	1	18
0	0	0	0	1	1	2
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1	4	12	2	9	2	30

DEMAND: 200, 300, 700, 800, 1500

STORAGE: 200, 300, 700, 800, 1500

Storage and demand in thousands of acre feet.

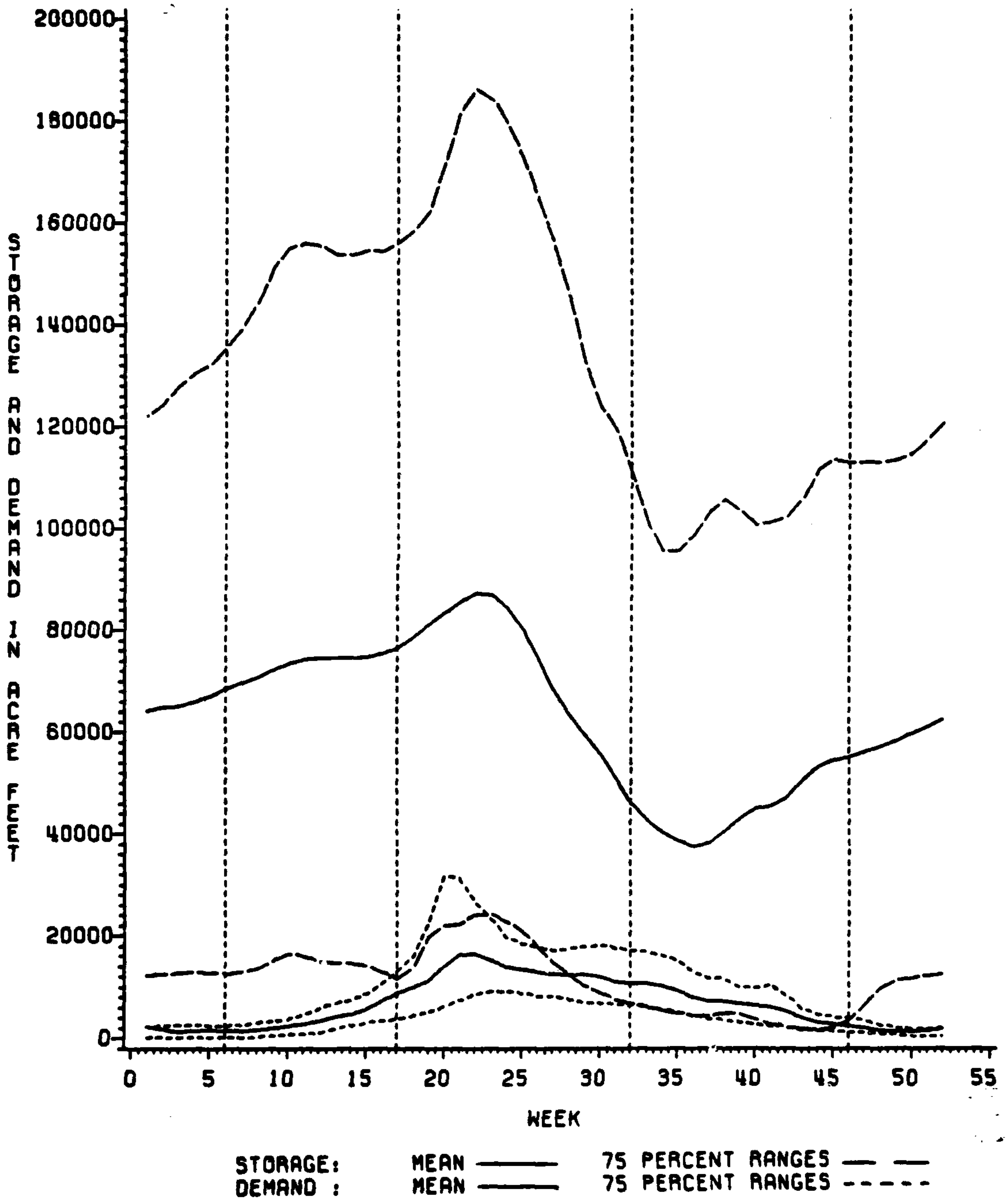

Figure 52. Storage and demand vs. time; long-term weekly means and 75 percent ranges for subbasin B23 of the North Fork of the Red River; storage and demand in acre feet per week.

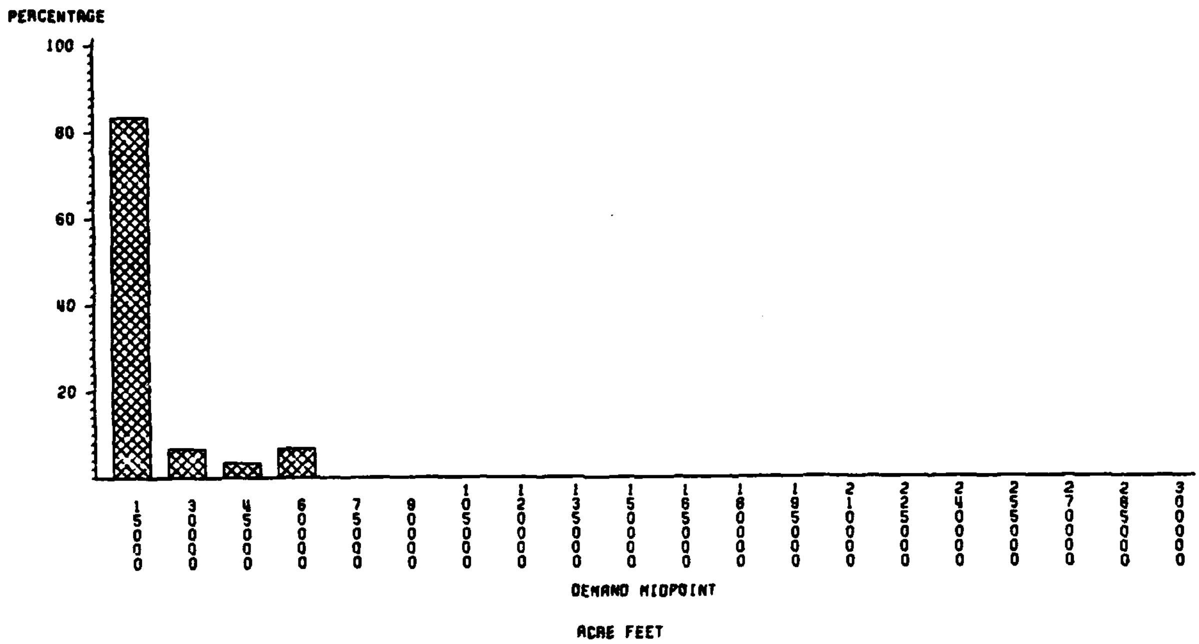

Figure 53a. Percentage frequency of demand for the middle of the excess period (week 6) for subbasin B23 of the North Fork of the Red River.

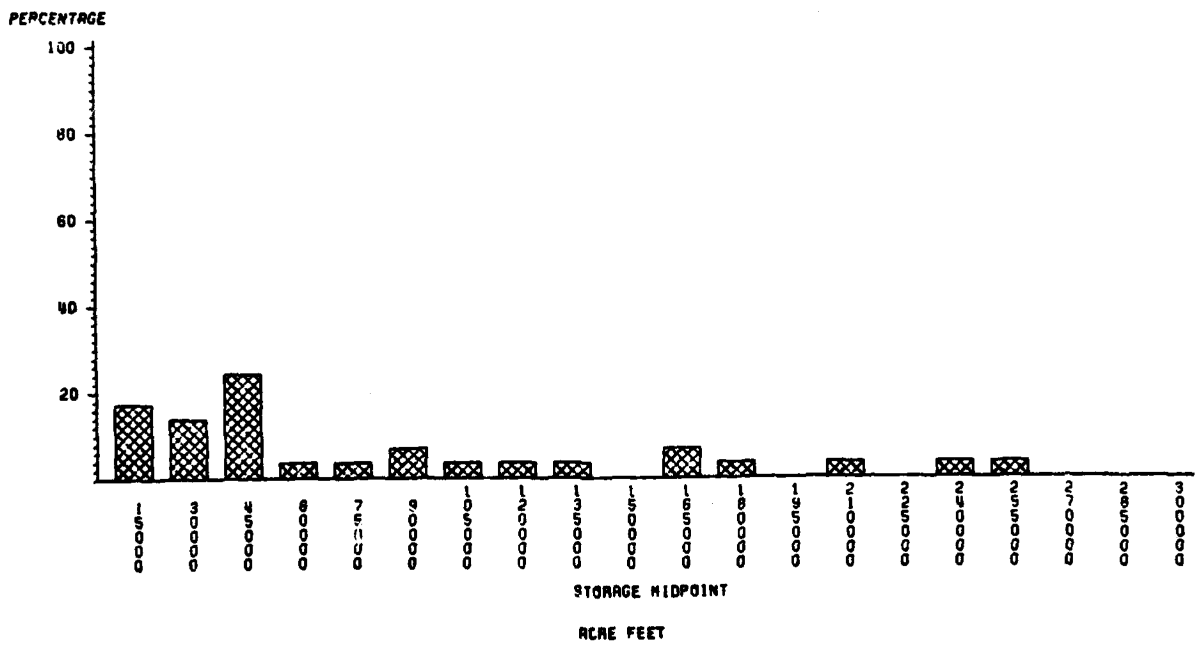

Figure 53b. Percentage frequency of storage for the middle of the excess period (week 6) for subbasin B23 of the North Fork of the Red River.

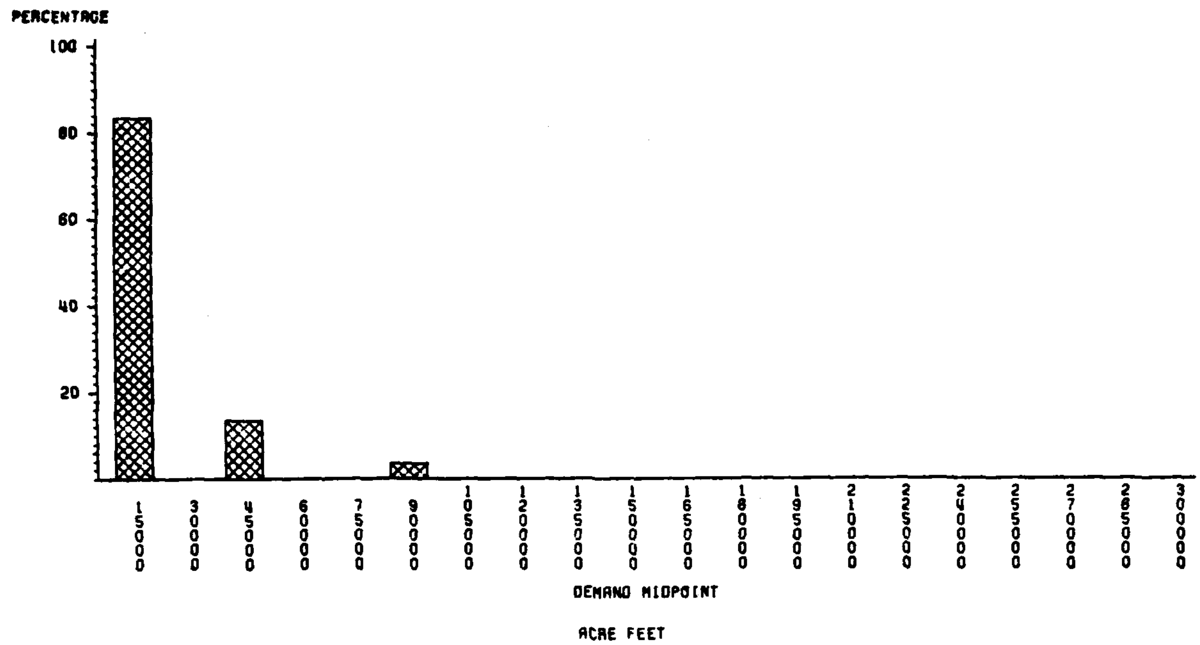

Figure 54a. Percentage frequency of demand for the middle of the deficit period (week 32) for subbasin B23 of the North Fork of the Red River.

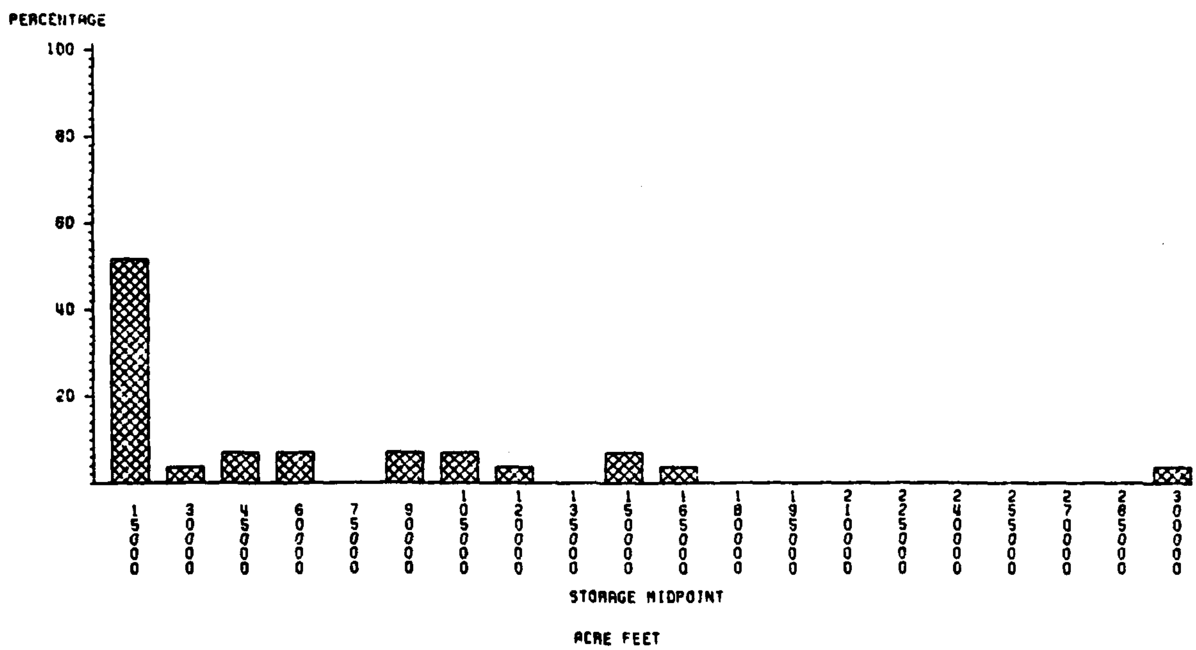

Figure 54b. Percentage frequency of storage for the middle of the deficit period (week 32) for subbasin B23 of the North Fork of the Red River.

Table 7. Joint frequency table for subbasin B23, week 6 (mid-excess period).

0	0	0	7	5	6	18
0	0	1	3	0	3	7
0	0	3	2	0	0	5
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	4	12	5	9	30

DEMAND: 1, 2, 12, 68, 136

STORAGE: 1, 2, 12, 68, 136

Storage and demand in thousands of acre feet.

Table 8. Joint frequency table for subbasin B23, week 32 (mid-deficit period).

1	0	2	0	0	0	3
0	0	0	0	0	0	0
1	0	8	5	3	3	20
0	0	0	2	2	1	5
0	0	0	0	2	0	2
0	0	0	0	0	0	0
2	0	10	7	5	4	30

DEMAND: 6, 8, 18, 46, 110

STORAGE: 6, 8, 18, 46, 110

Storage and demand in thousands of acre feet.

5.5 Case Studies

Climatic variables, such as have been dealt with in this thesis (e.g., long-term mean weekly precipitation) are very useful tools for study. However, we do not ever experience an "average" climatic year, any more than a particular family has the "average" 2.3 children. For that reason, as this study concludes, we examine three individual years of storage and demand values for two separate subbasins. Little attempt will be made to generalize from these two subbasins to the entire study area. The purpose of the case studies is to examine the range of variation in mean values that are experienced in individual years in individual areas.

Subbasin B13 (about in the middle of the North Canadian study area) and B21 (the western-most in the North Fork study area) were selected because they illustrated types of variability and error which appear common and significant. There is considerable variability from subbasin to subbasin in a particular year. For that reason a full set of case study graphs (3 years for each subbasin) is included as part of Appendix C.

The three years chosen for study, 1956, 1959 and 1980, were selected because they contained a variety of possible circumstances. For most of Oklahoma, 1956 was the second or third consecutive year of drought. The five-year period from 1952 through 1956 was the driest five consecutive years on record in Oklahoma, drier even than any five years in the 1930's. On the other hand the next five years, 1957 through 1961, were the wettest five consecutive years on record. The

second year selected was 1959, in the middle of this wet period.[7] The last year, 1980, was selected for three reasons. First, it is recent enough that most people still have vivid subjective impressions about the year's weather. Secondly, it was selected to illustrate what an "average" climatic year might look like under scrutiny. In most of the western one half of Oklahoma, for example, annual precipitation was close to the long-term mean in 1980. This is because the first half of the year was very wet, and the second half very, very dry. Lastly, 1980 was selected to illustrate the fragile nature of the water balance in western Oklahoma. As we will see, spring storage that was greater than the 75 percent empirical storage range fell to below that range in six months.

5.5.1 Subbasin B21 of the North Fork

In subbasin B21 1956 was a dry year. Storage for 1956 ran at or below the long-term 75 percent range (Figure 55). In Figure 56 we see that after early February, storage decreased continuously throughout the year, with no sign of a late summer and fall recovery. The demand (Figure 56) was below the long-term mean value almost the entire year. Figure 57 shows there was a deficit from early June through most of November with only brief intervals of excess, a total of almost six months!

Storage for 1959 was at or above the long-term mean most of the year and jumped to above the 75 percent range in late fall (Figure 58).

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[7]Discussion of historical wet and dry periods, except 1980, is from Curry, 1973.

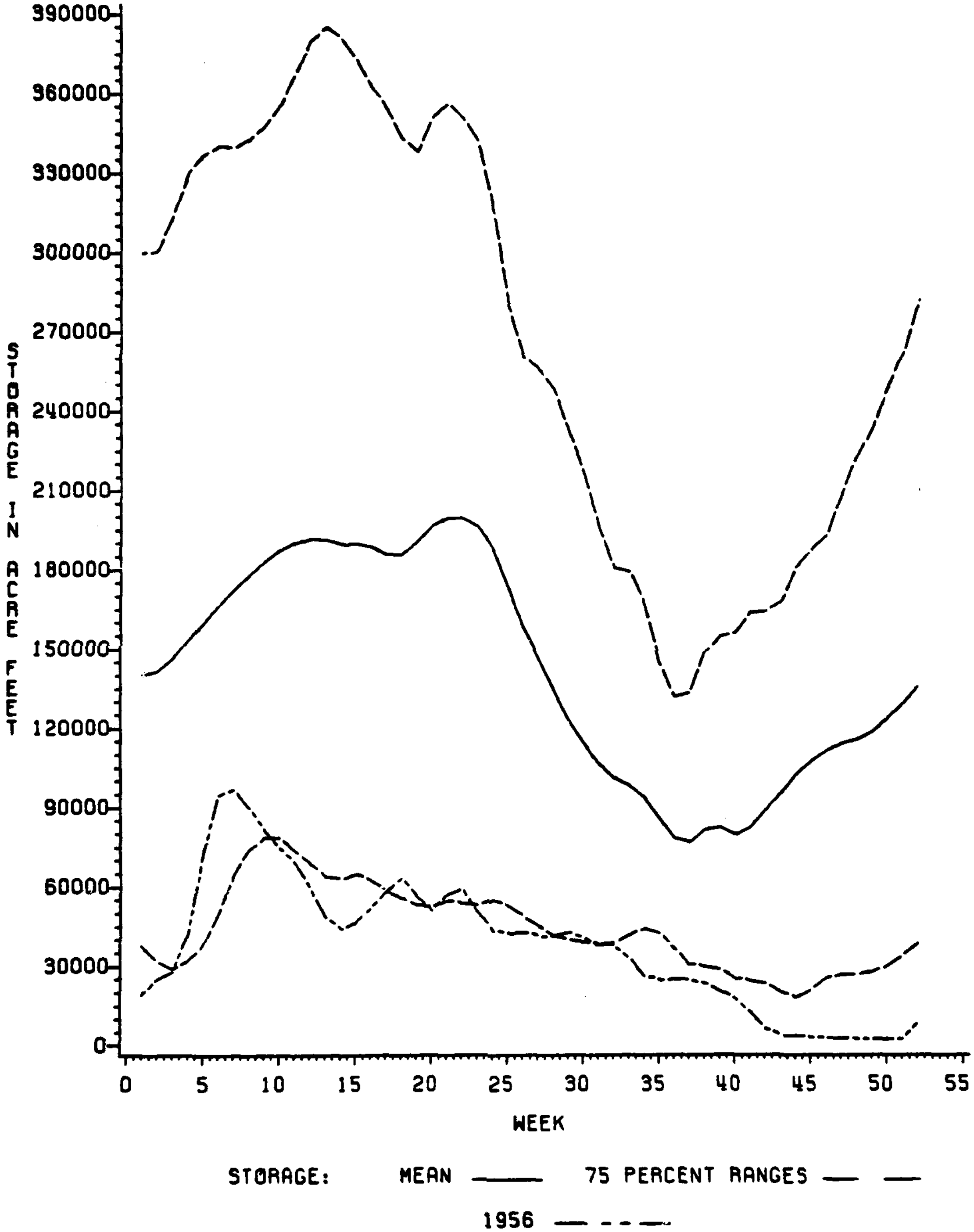


Figure 55. Storage vs. time; long-term weekly means, 75 percent ranges and 1956 weekly means for subbasin B21 of the North Fork of the Red River; storage in average acre feet per week.

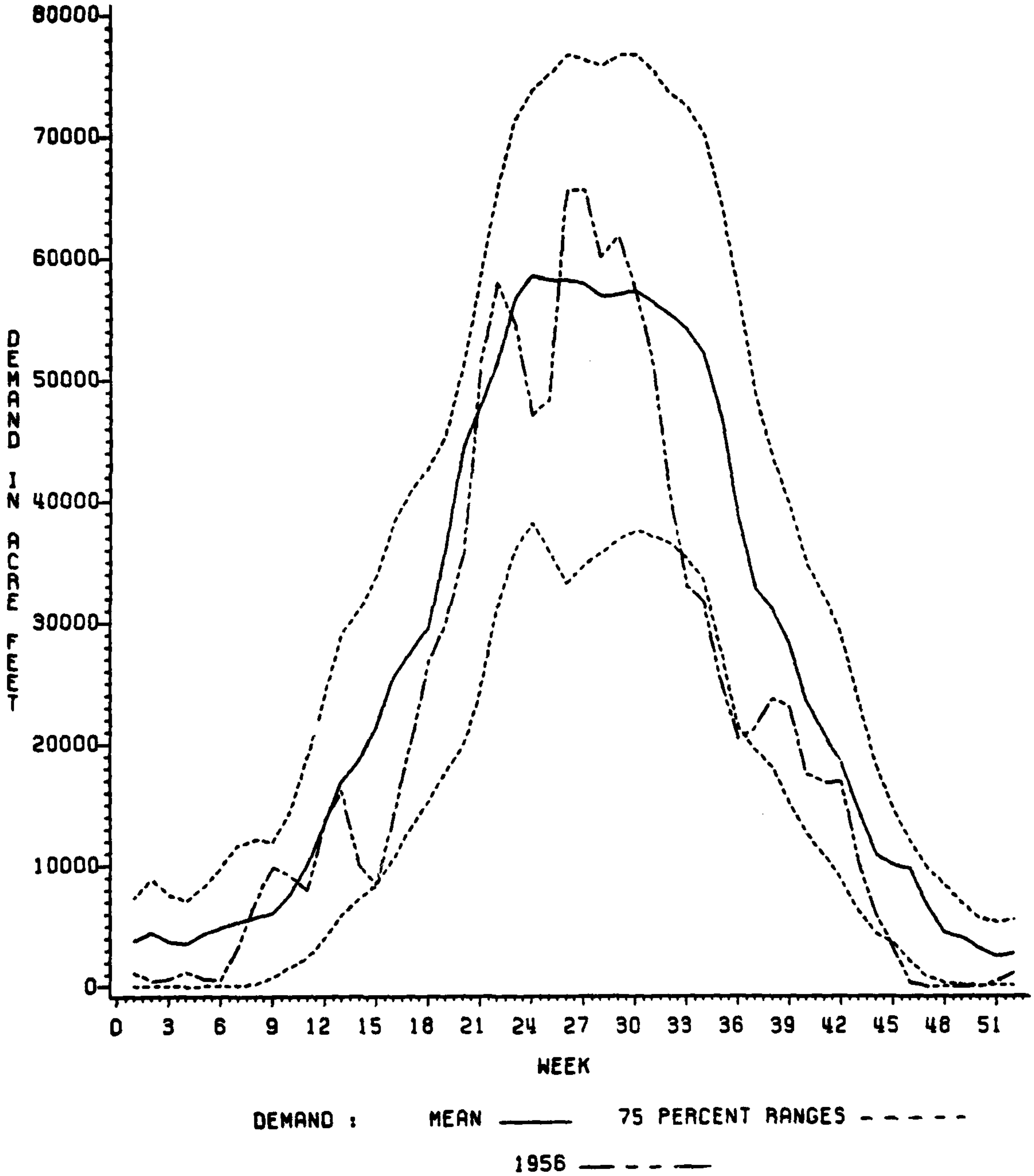


Figure 56. Demand vs. time; long-term weekly means, 75 percent ranges and 1956 weekly means for subbasin B21 of the North Fork of the Red River; demand in acre feet per week.

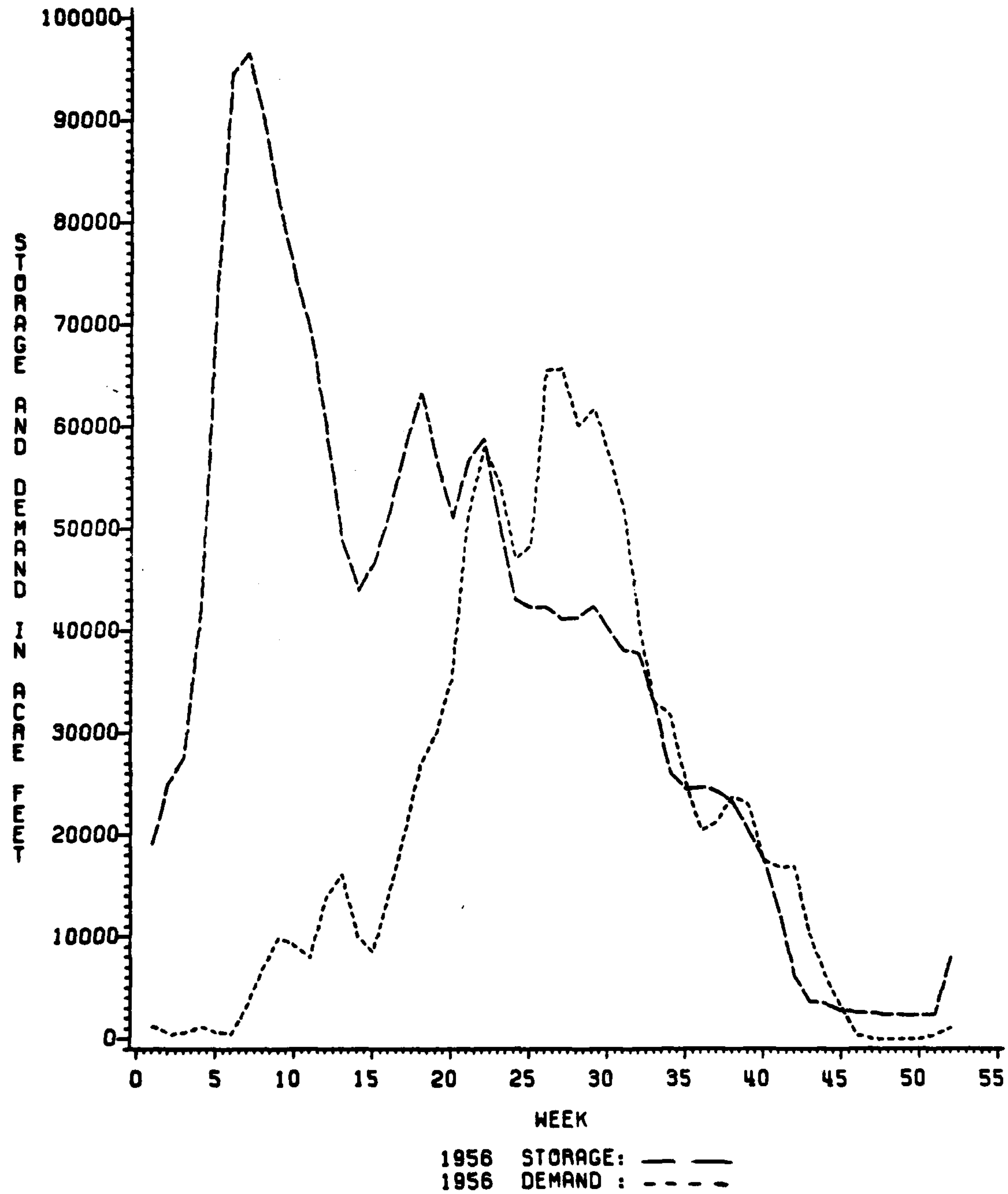


Figure 57. Storage and demand vs. time; 1956 weekly means for subbasin B21 of the North Fork of the Red River; storage and demand in acre feet per week.

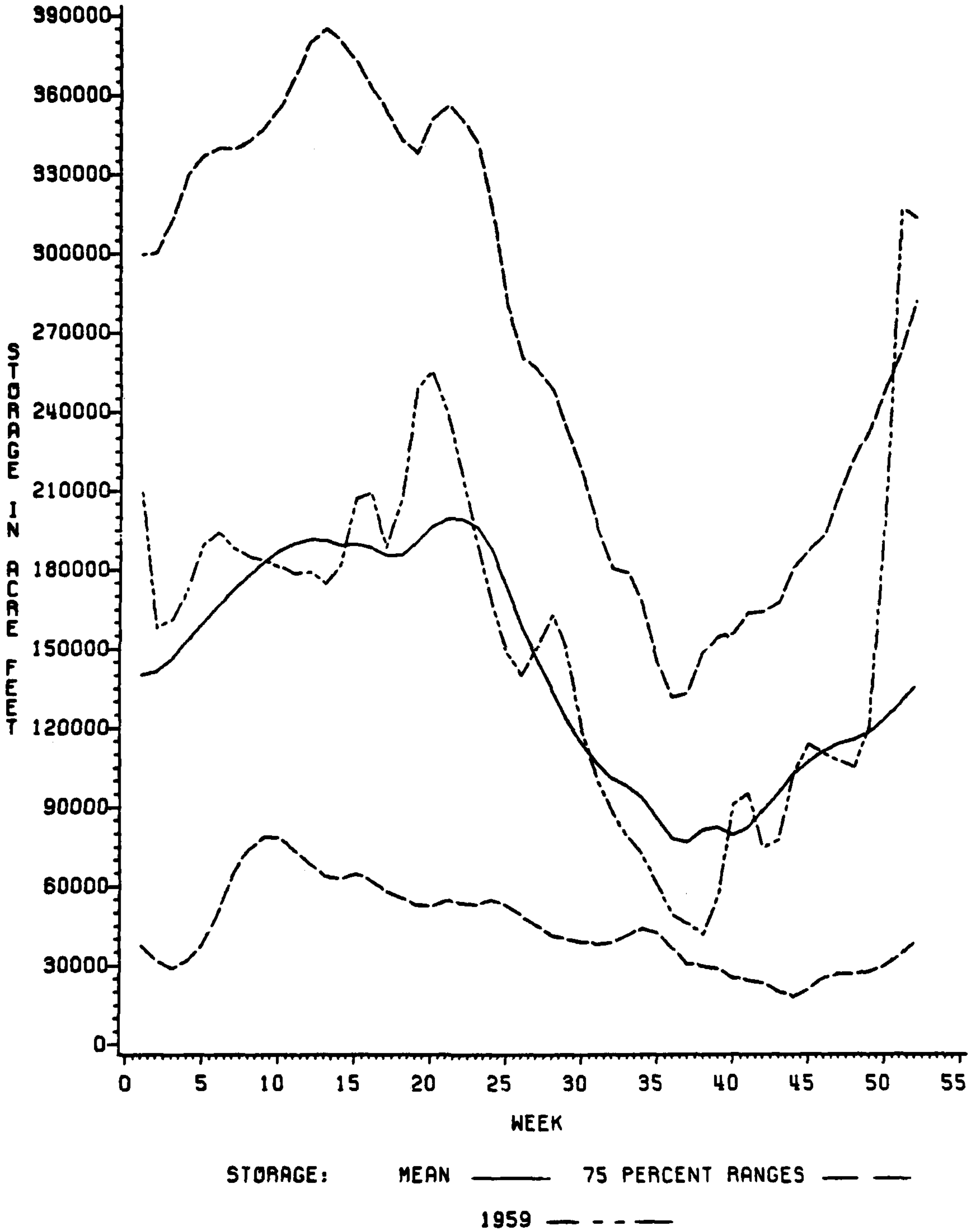


Figure 58. Storage vs. time; long-term weekly means, 75 percent ranges and 1959 weekly means for subbasin B21 of the North Fork of the Red River; storage in average acre feet per week.

The increase was so great that the year ended with storage twenty percent above the late spring maximum for that year. Due to greater moisture availability, demand (Figure 59) was much closer to the potential maximum (PET) in early summer. Figure 60 indicates clearly that there was no deficit in 1959.

In 1980 storage began at the climatological average (150,000 AF or 2.6 inches). Heavier than normal spring rains pushed storage above the 75 percent range to a maximum at week 20 (375,000 AF or 6.4 inches) (Figure 61). Note that the maximum soil moisture or available water capacity (AWC) for this area was defined in the hydrologic accounting system to be seven inches. Demand (Figure 62) was greater than normal in the early summer because of greater moisture availability. The normal summer decrease in storage began about week 22 but, with no late summer rains, it continued until it has had decreased to below the 75 percent range, or to about 10,000 AF (0.2 inches). Here we see that almost record excess became almost record shortage in less than five months. Figure 63 verifies that a deficit did occur in 1980, for about four weeks.

5.5.2 Subbasin B13 of the North Canadian

The case study for subbasin B21 illustrated the change in the storage and demand picture for wet, dry and "average" years. Subbasin B13, which contains Canton Lake, illustrates something probably just as important; that is, the sensitivity of the storage and demand calculations to missing or erroneous data.

Figure 64 shows the long-term mean weekly storage, 75 percent

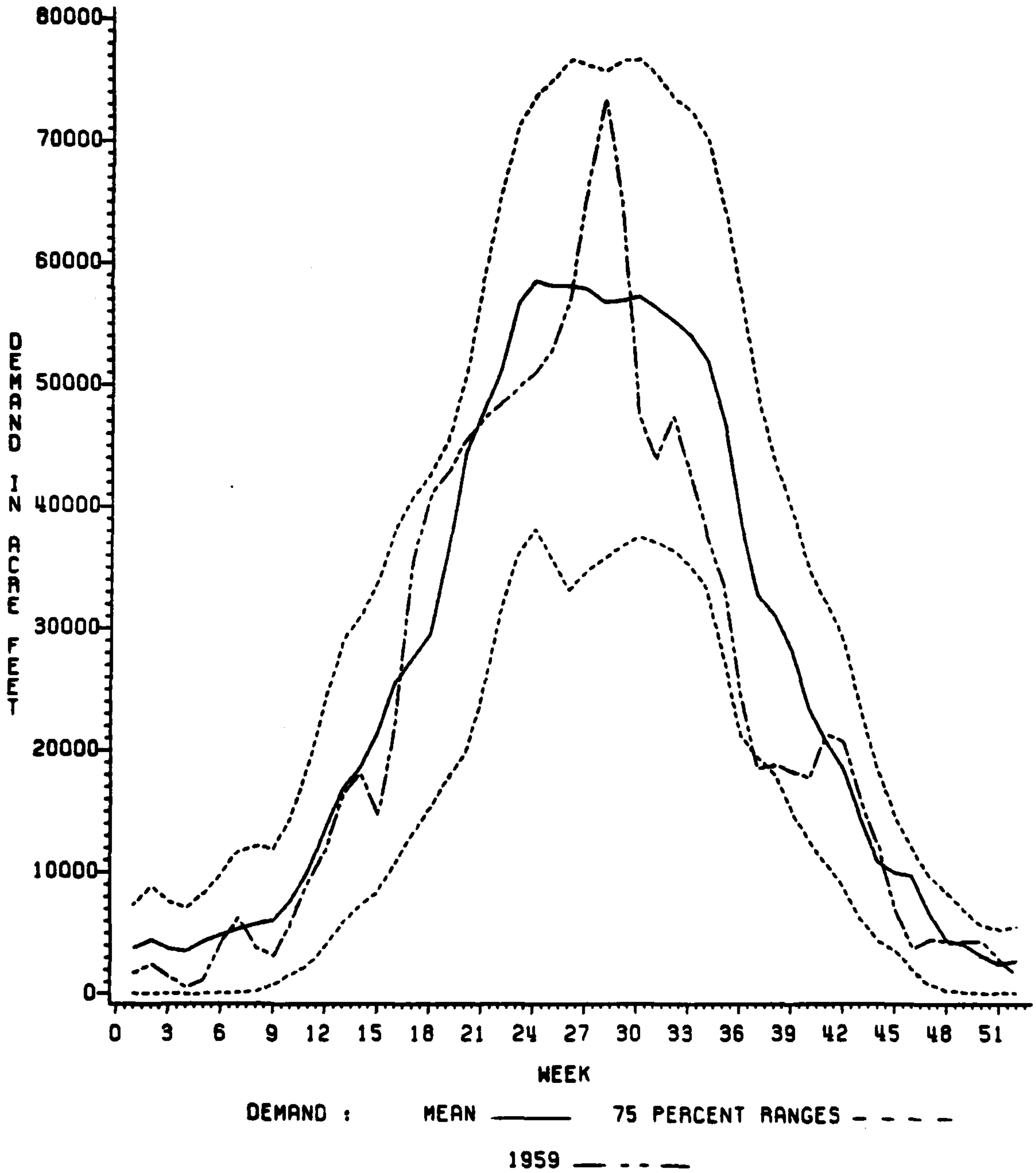


Figure 59. Demand vs. time; long-term weekly means, 75 percent ranges and 1959 weekly means for subbasin B21 of the North Fork of the Red River, demand in acre feet per week.

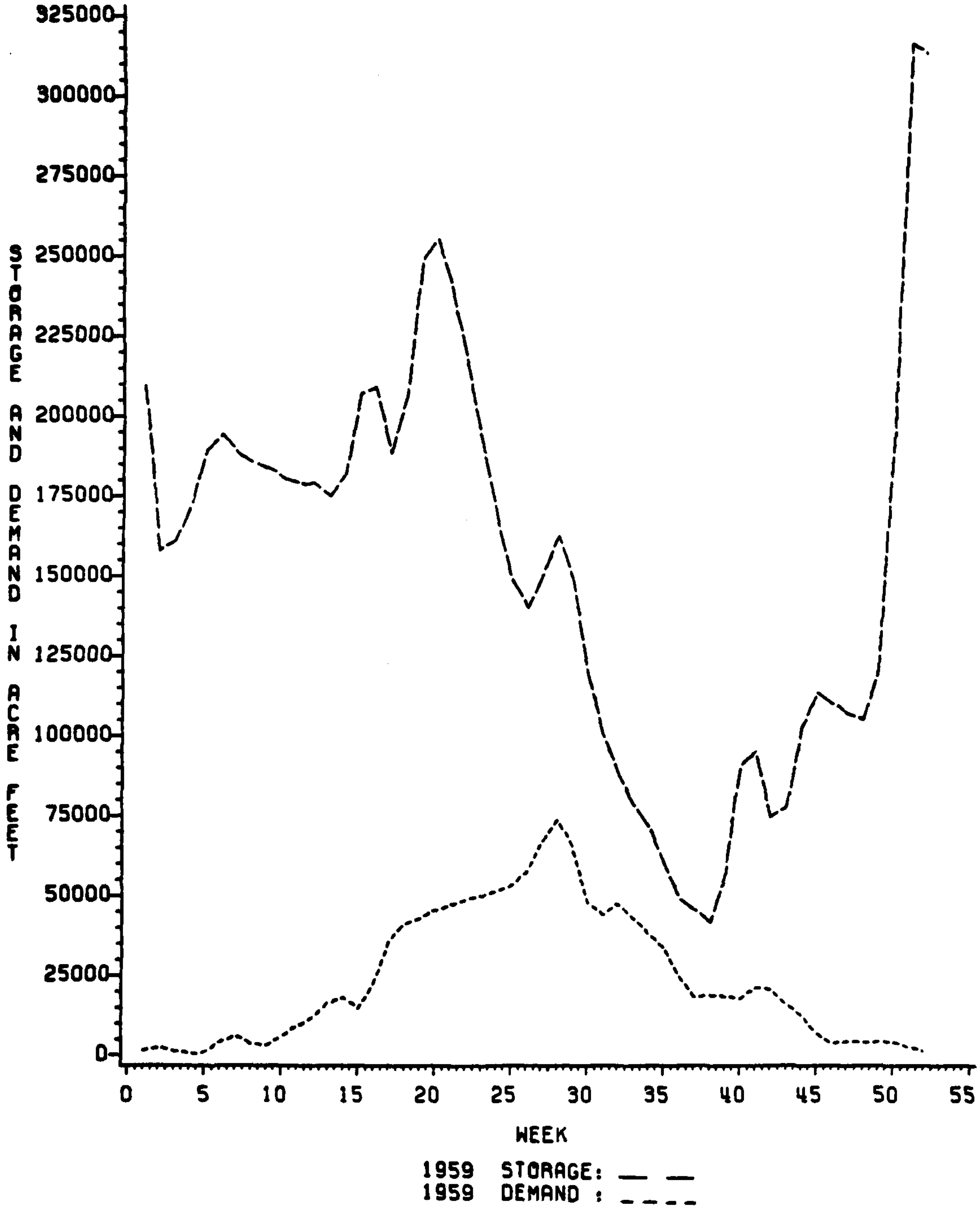


Figure 60. Storage and demand vs. time; 1959 weekly means for subbasin B21 of the North Fork of the Red River; storage and demand in acre feet per week.

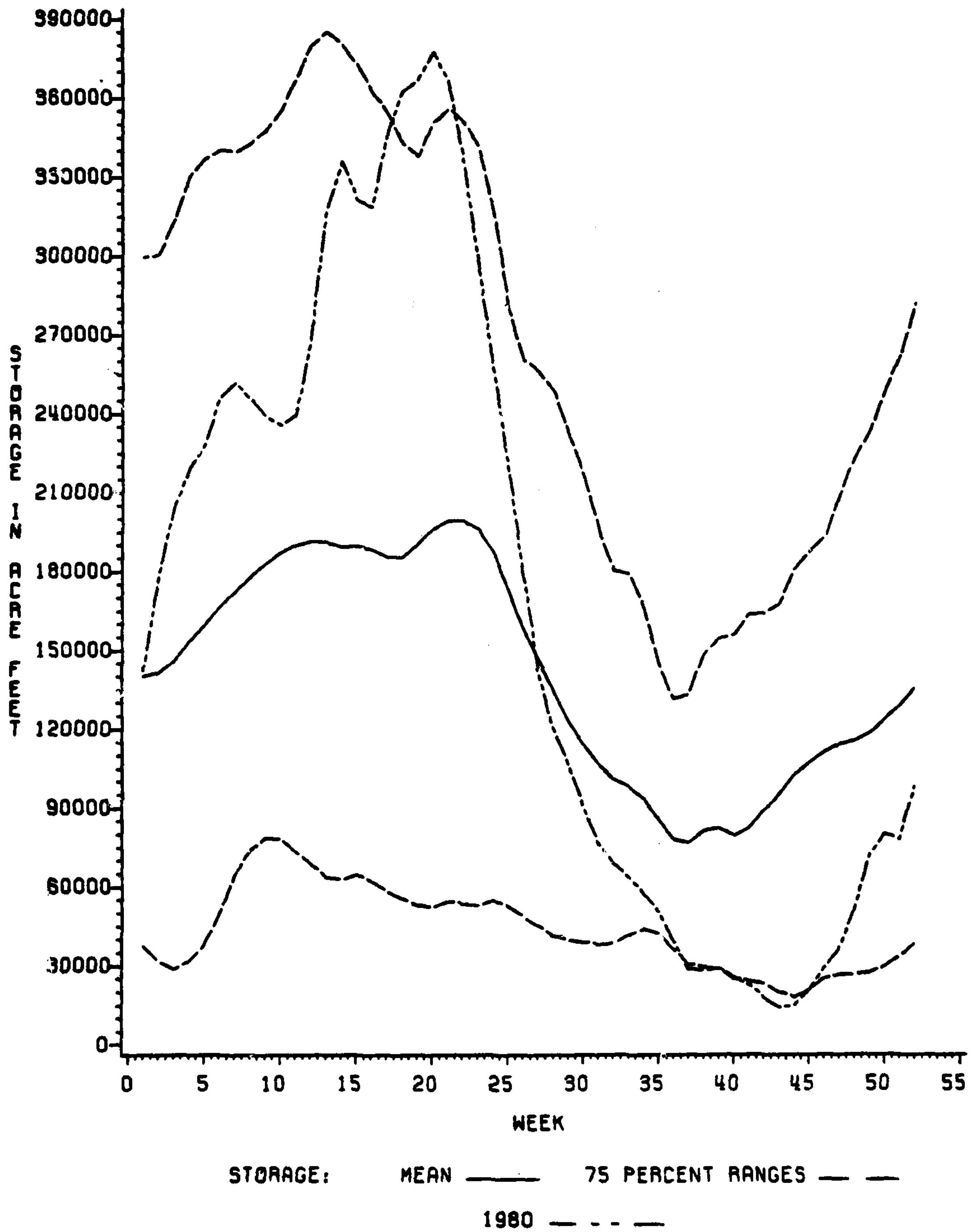


Figure 61. Storage vs. time; long-term weekly means, 75 percent ranges and 1980 weekly means for subbasin B21 of the North Fork of the Red River; storage in average acre feet per week.

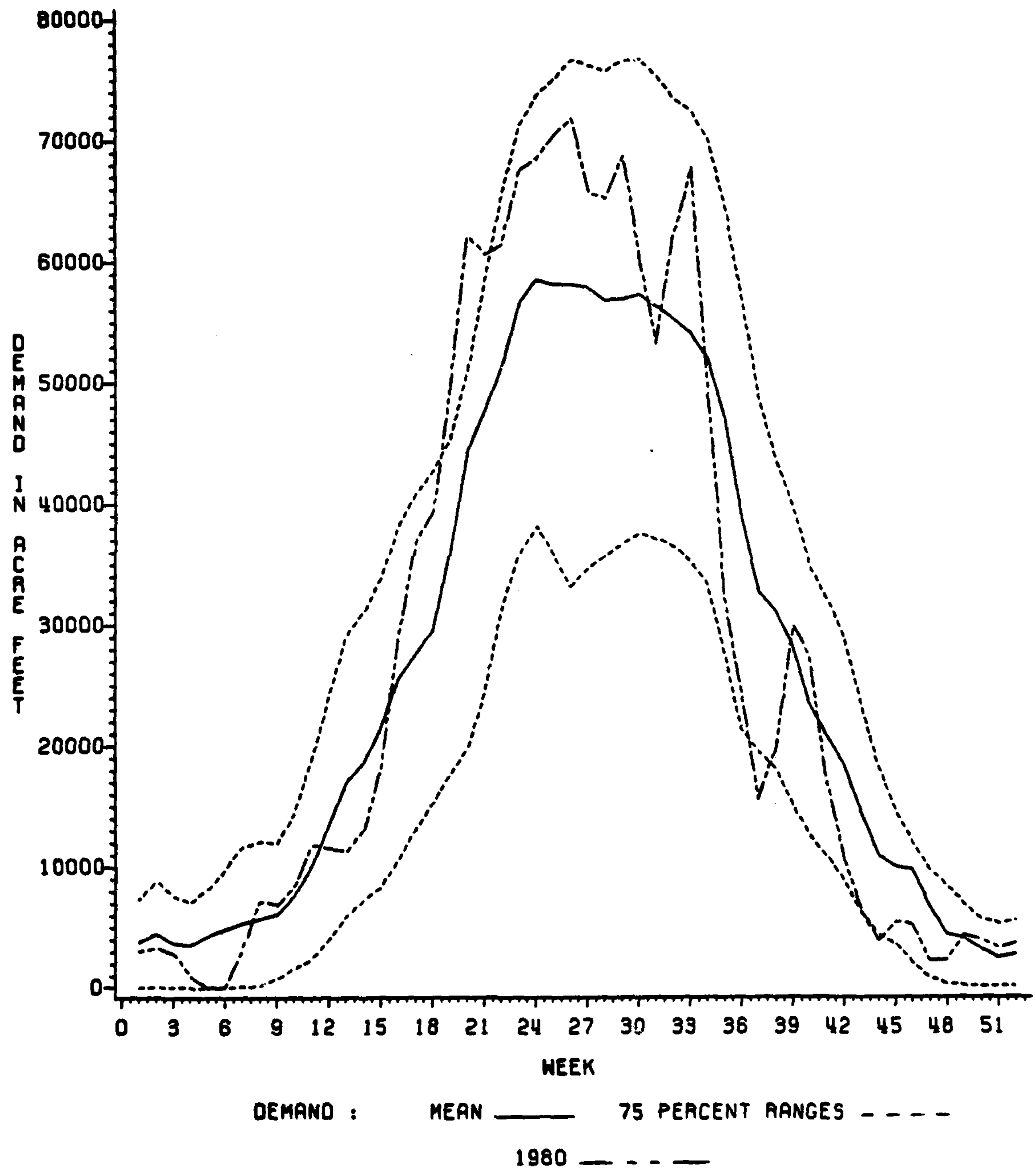


Figure 62. Demand vs. time; long-term weekly means, 75 percent ranges and 1980 weekly means for subbasin B21 of the North Fork of the Red River; demand in acre feet per week.

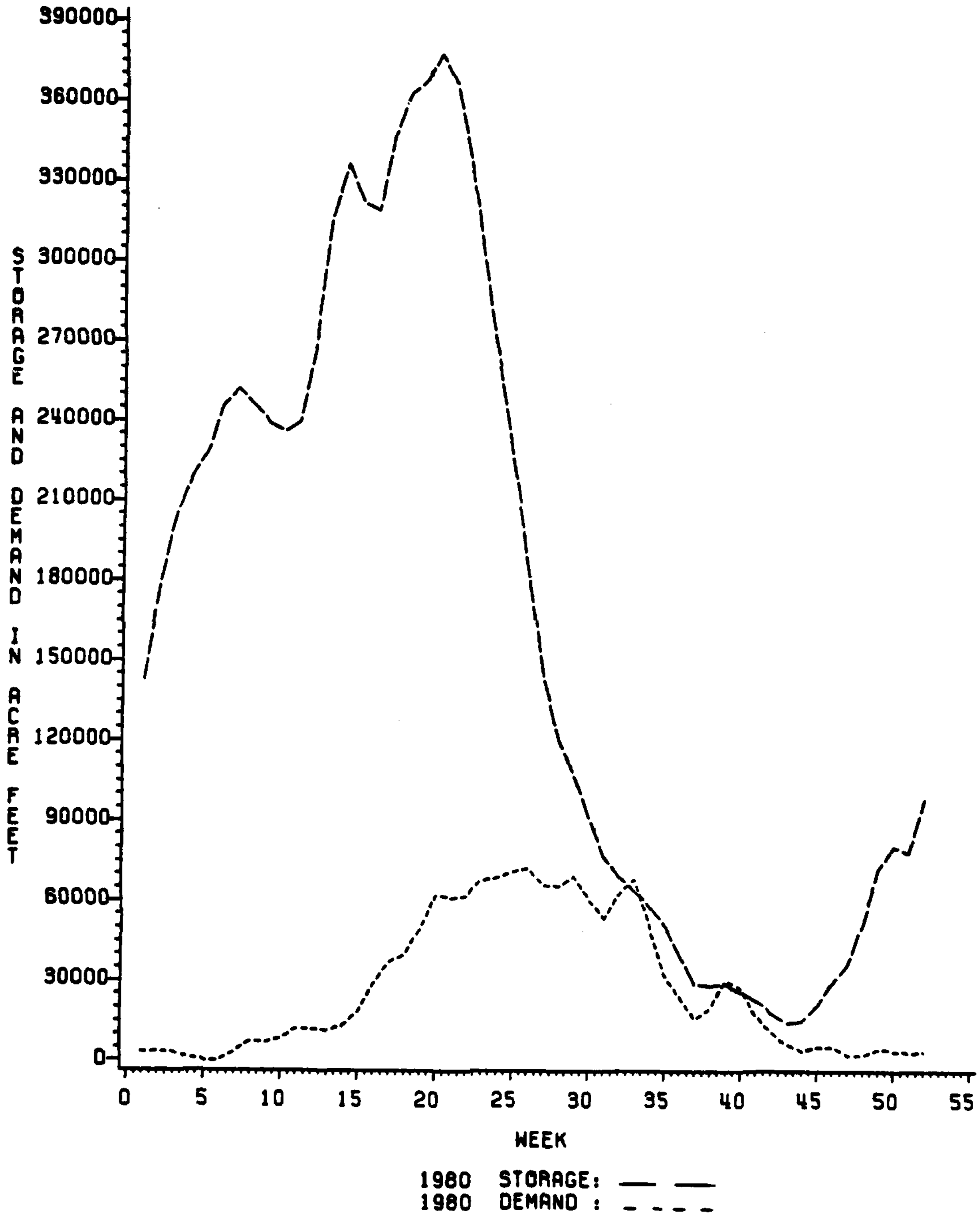


Figure 63. Storage and demand vs. time; 1980 weekly means for subbasin B21 of the North Fork of the Red River; storage and demand in acre feet per week.

ranges and the calculated storage for 1956. Since 1956 was a dry year, it is not surprising that the 1956 storage is well below the long-term mean, and, in fact, it closely parallels the bottom of the 75 percent range. It is not surprising, but it is not entirely correct. Recall from Equation (4.7) that storage is defined as

$$S = SM + LC + CC ,$$

where S is storage, SM is soil moisture, LC is lake contents and CC is channel contents. Channel contents is the sum of stream contents (SC) and net channel gain (-CL). We have seen previously that the dominant components of storage are SM and LC. However, although Canton Lake existed in 1956, contents data were not available. Therefore, the calculated 1956 storage, which only considered SM, underestimated the actual storage (unless, of course, the lake was dry). A fourth line in Figure 64 is an adjusted 1956 storage. It was computed by graphically adding an appropriate adjustment factor (one-half of the 15-year mean contents for Canton Lake (Figure 37)) to the 1956 storage value. One-half of the mean contents was used because the period of record for lake contents is 1966-1980 (15 years of the 30-year study period). This adjusted 1956 storage is only a gross estimate and probably overestimates the actual 1956 storage. We have no reason to assume that mean lake contents from 1951-1965 were the same as those from 1966-1980. They were probably not. For instance, we know that four of the five driest years from 1951-1980 occurred prior to 1966. The actual 1956 storage values, then, most likely fall between the two 1956 storage curves on Figure 64. Using either estimate of the 1956 storage, however, it is

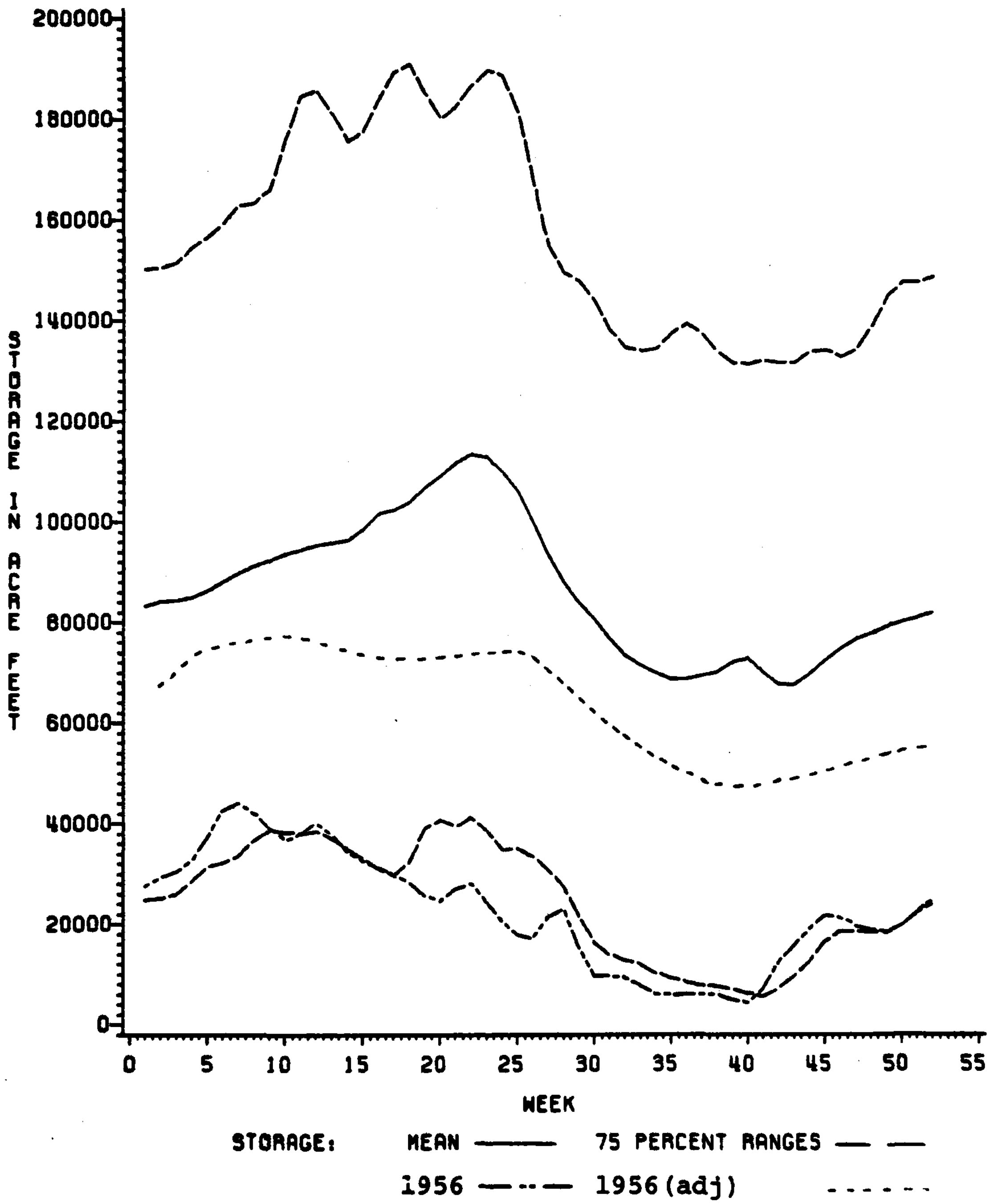


Figure 64 . Storage vs. time; long-term weekly means, 75 percent ranges and 1956 weekly means for subbasin B13 of the North Canadian River; storage in average acre feet per week.

apparent that storage for the year was below the mean. We can see, from this example, the sensitivity of storage (as calculated in this study) to missing or erroneous data (in this case, missing lake contents).

Figure 65 shows long-term mean weekly demand and actual 1956 demand. Demand was defined in Equation (4.8) as

$$D = ET + SE + LE + CL \ ,$$

where D is demand, ET is evapotranspiration, SE is the stream evaporation term, LE is lake evaporation and CL is channel loss. Channel loss was defined in Equation (4.6) as

$$CL = RO - SE - SO + SI - \Delta LC \ ,$$

where CL is channel loss, RO is runoff, SE is the stream evaporation term, SO is stream outflow, SI is stream inflow and ΔLC is change in lake contents. The demand in 1956 stays between the long-term mean value and the lower range, except for a total of five weeks at the beginning of the year. Figure 66 which is storage and demand for 1956 indicates there was a water deficit (demand greater than storage) from week 30 to week 40 (the end of July to the first of October). However, in light of the problems above, this conclusion could be somewhat suspect.

The situation in 1959 is shown in Figure 67 (storage), Figure 68 (demand) and Figure 69 (storage and demand). The calculated 1959 storage appears lower than expected, considering 1959 was a very wet year. However, as in 1956, contents information for Canton Lake was not available, so adjusted 1959 storage values were estimated (using the same procedure as for 1956). These adjusted storage values are

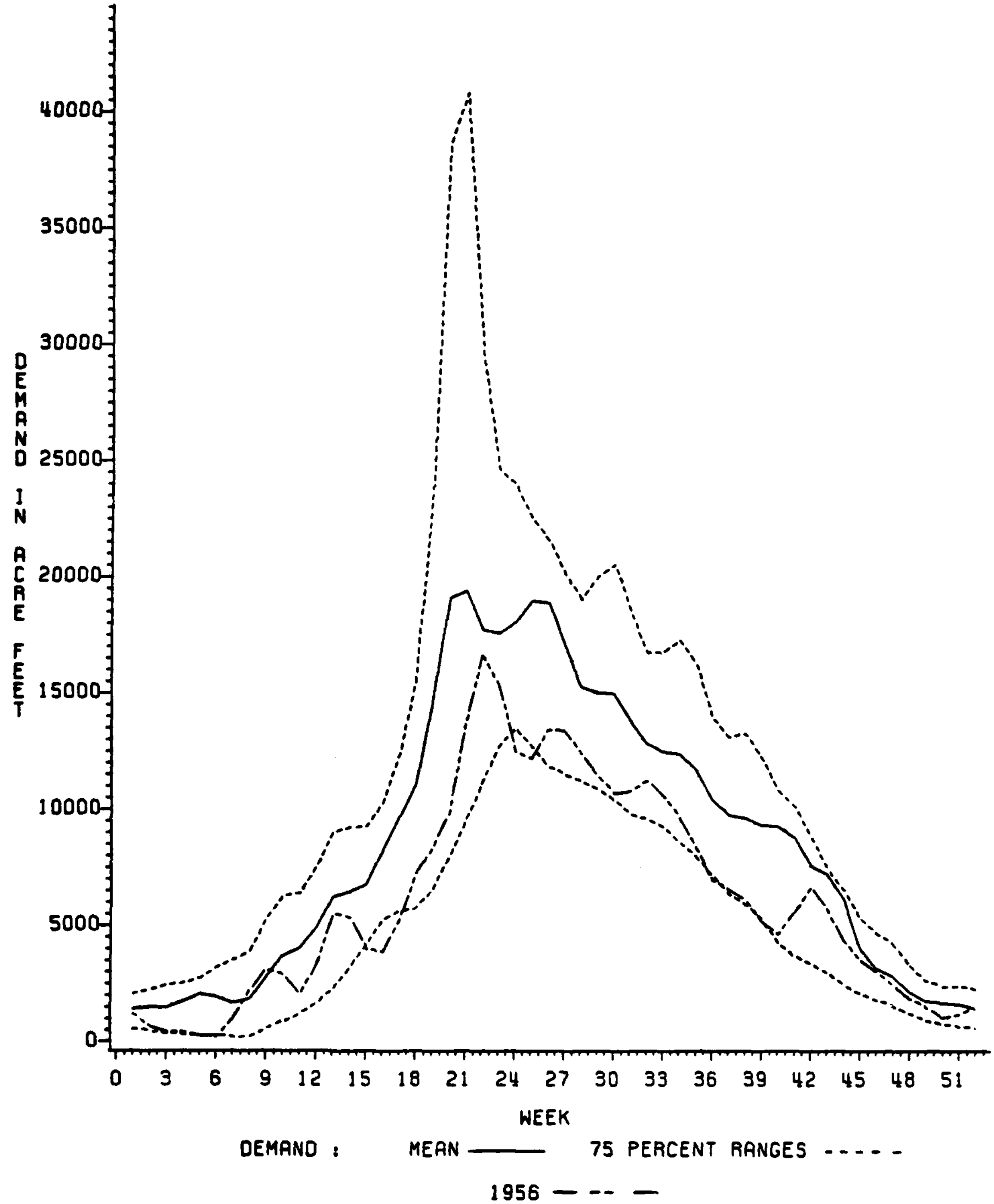


Figure 65. Demand vs. time; long-term weekly means, 75 percent ranges and 1956 weekly means for subbasin B13 of the North Canadian River; demand in acre feet per week.

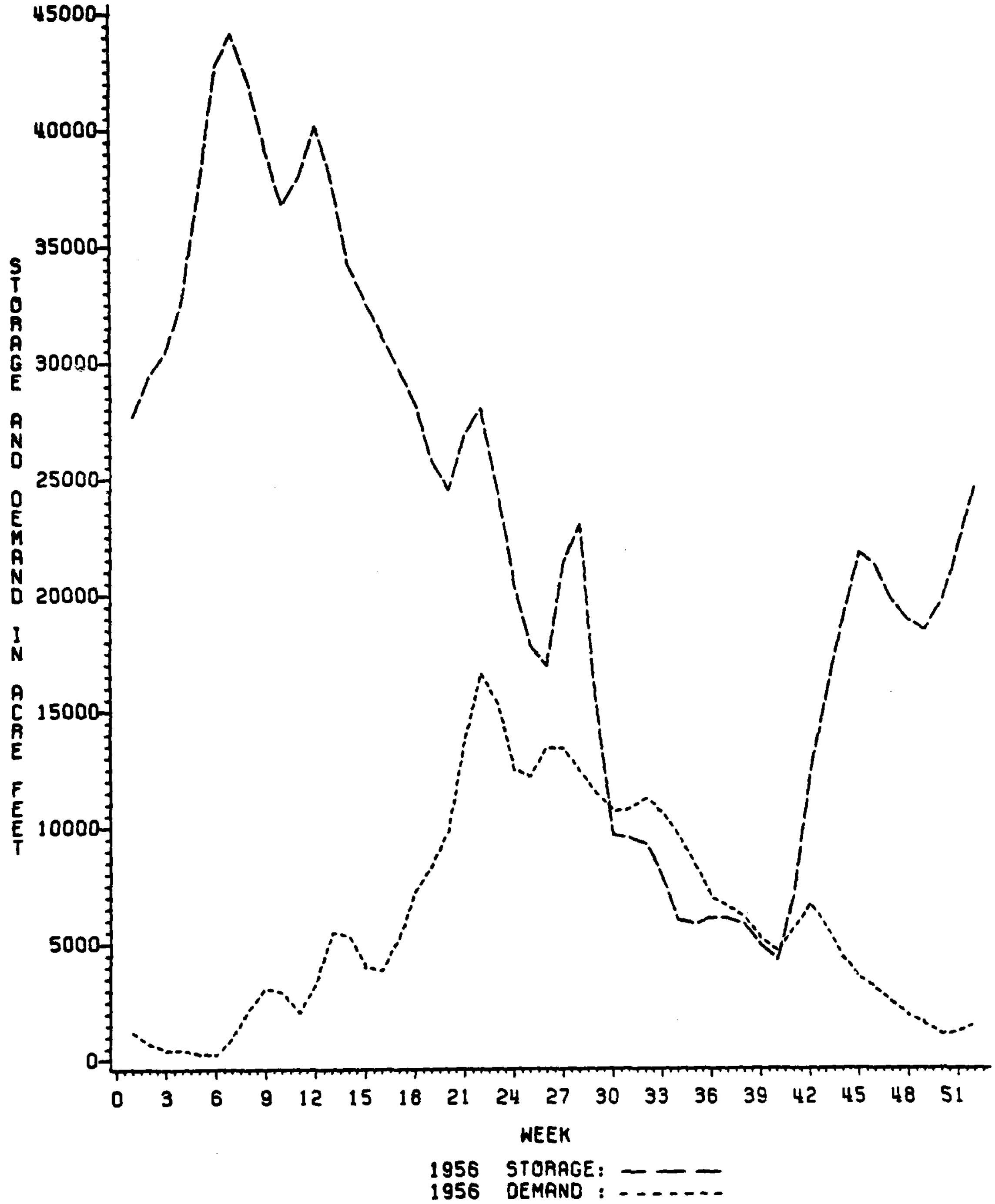


Figure 66. Storage and demand vs. time; 1956 weekly means for subbasin B13 of the North Canadian River; storage and demand in acre feet per week.

probably closer to the truth than the originally plotted values, but their accuracy is still suspect. Since 1959 was a very wet year, the adjusted values may be an underestimate. Considering the adjusted values, we observe the 1959 storage began about average, increased in the late spring, and then decreased in early summer; all following the normal yearly pattern for storage. The unusual feature is the dramatic increase in late September (weeks 39 and 40). This was the result of very heavy precipitation (12.4") over the basin in those two weeks.

The demand curve for 1959 (Figure 68) is unusual because of the very dramatic peak for weeks 39 and 40. In fact, this demand peak is not real. Precipitation enters the demand equation through runoff in the channel loss term. In most basins, even unusually large runoff would be balanced by the stream contents terms (SI-SO), and the demand would not show a dramatic peak. Since this subbasin contains a lake, runoff, if not completely balanced by stream contents, would be offset by the change in lake contents. This probably occurred, but the contents for Canton Lake in 1959 are not known. As we saw previously with storage, we can clearly see the sensitivity of demand (through the channel loss term) to erroneous or missing lake data.

Figure 69 (1959 storage and demand) indicates that a water deficit did not exist in 1959. This is almost assuredly correct since the demand peak has been shown to be incorrect, and the storage values have been suggested to be underestimates.

In 1980 we observe a different manifestation of erroneous data. Contents information for Canton Lake were available for 1966-1980, therefore, Figure 70 (storage) should be accurate. The rapid

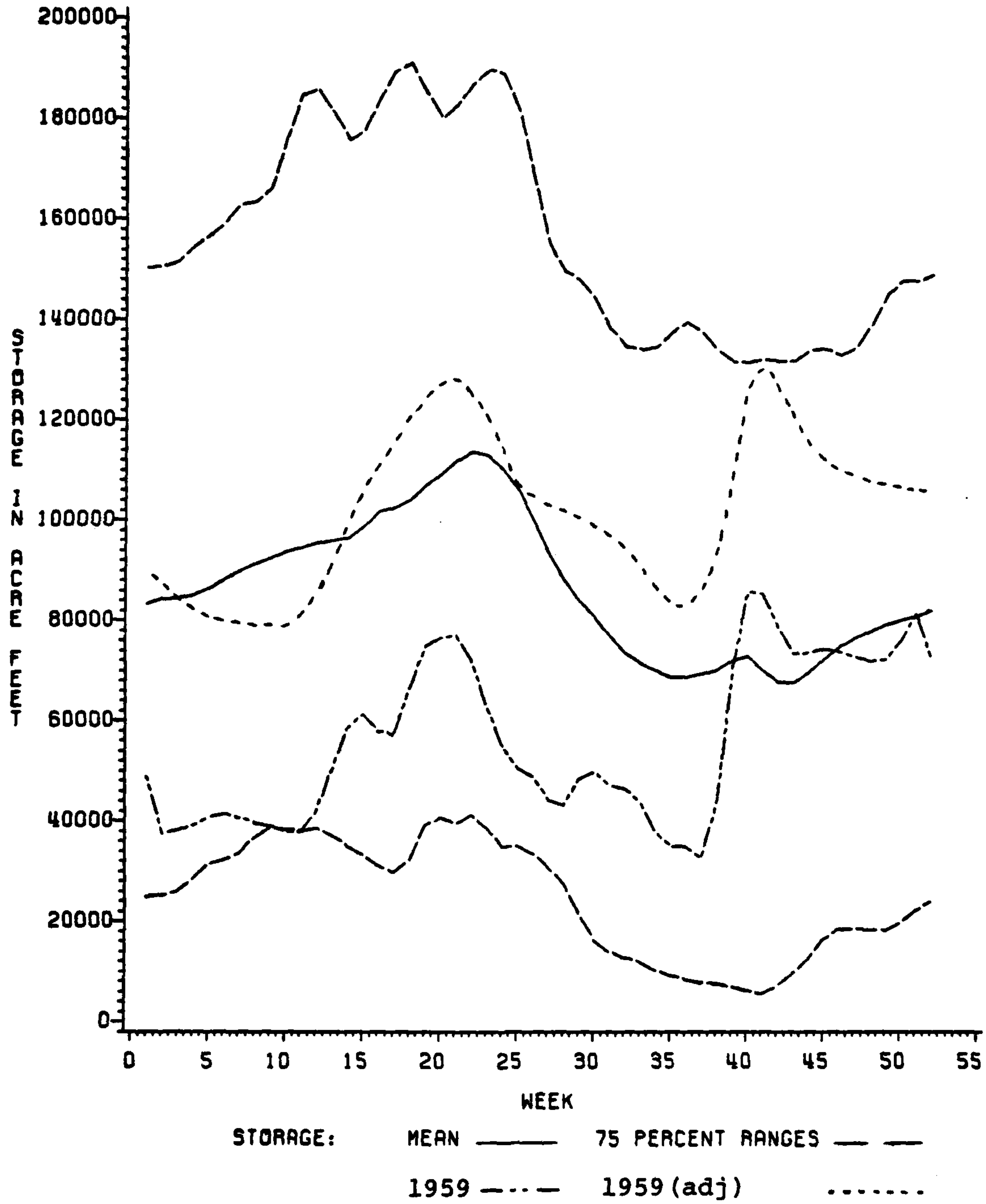


Figure 67 . Storage vs. time; long-term weekly means, 75 percent ranges and 1959 weekly means for subbasin B13 of the North Canadian River; storage in average acre feet per week.

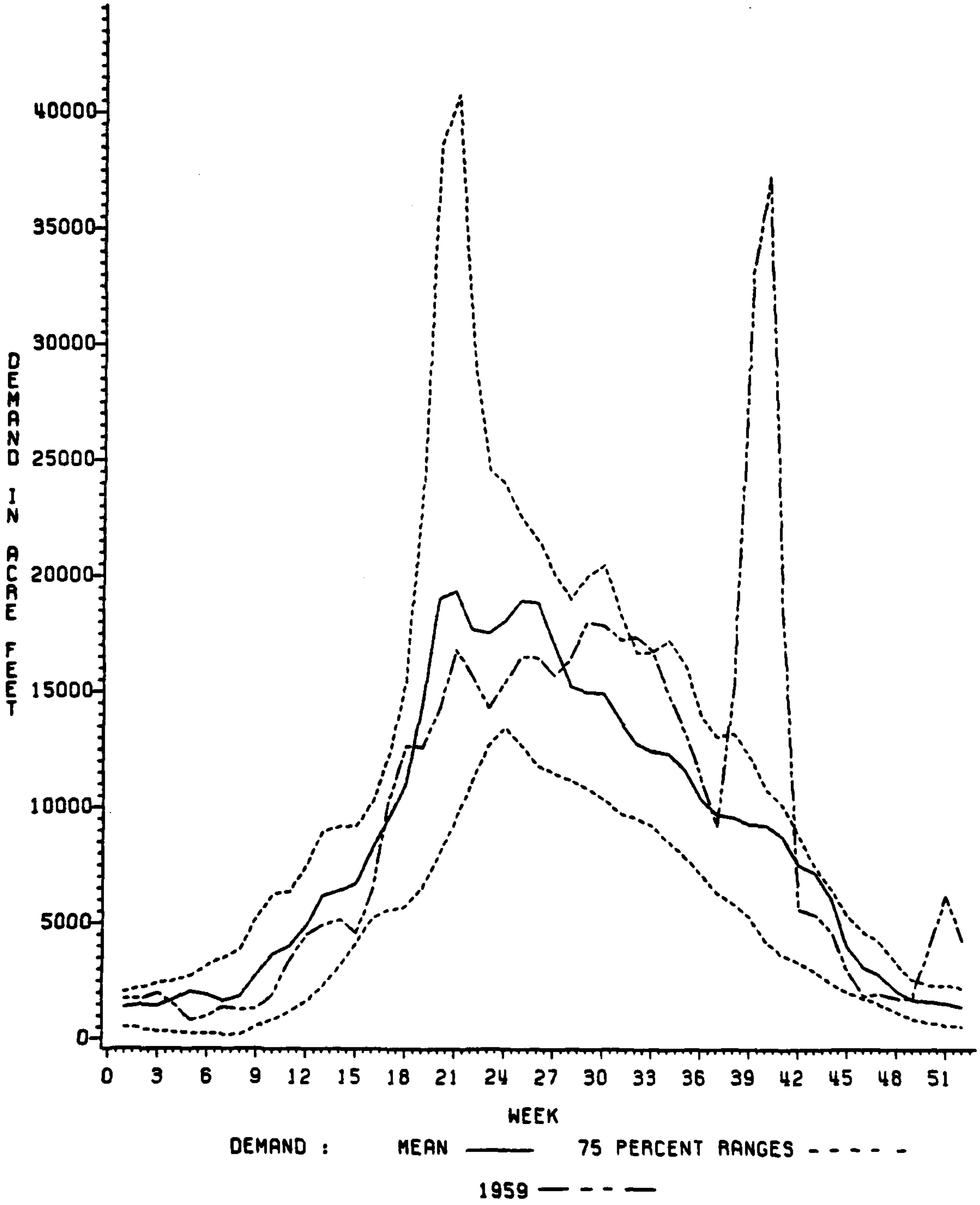


Figure 68. Demand vs. time; long-term weekly means, 75 percent ranges and 1959 weekly means for subbasin B13 of the North Canadian River; demand in acre feet per week.

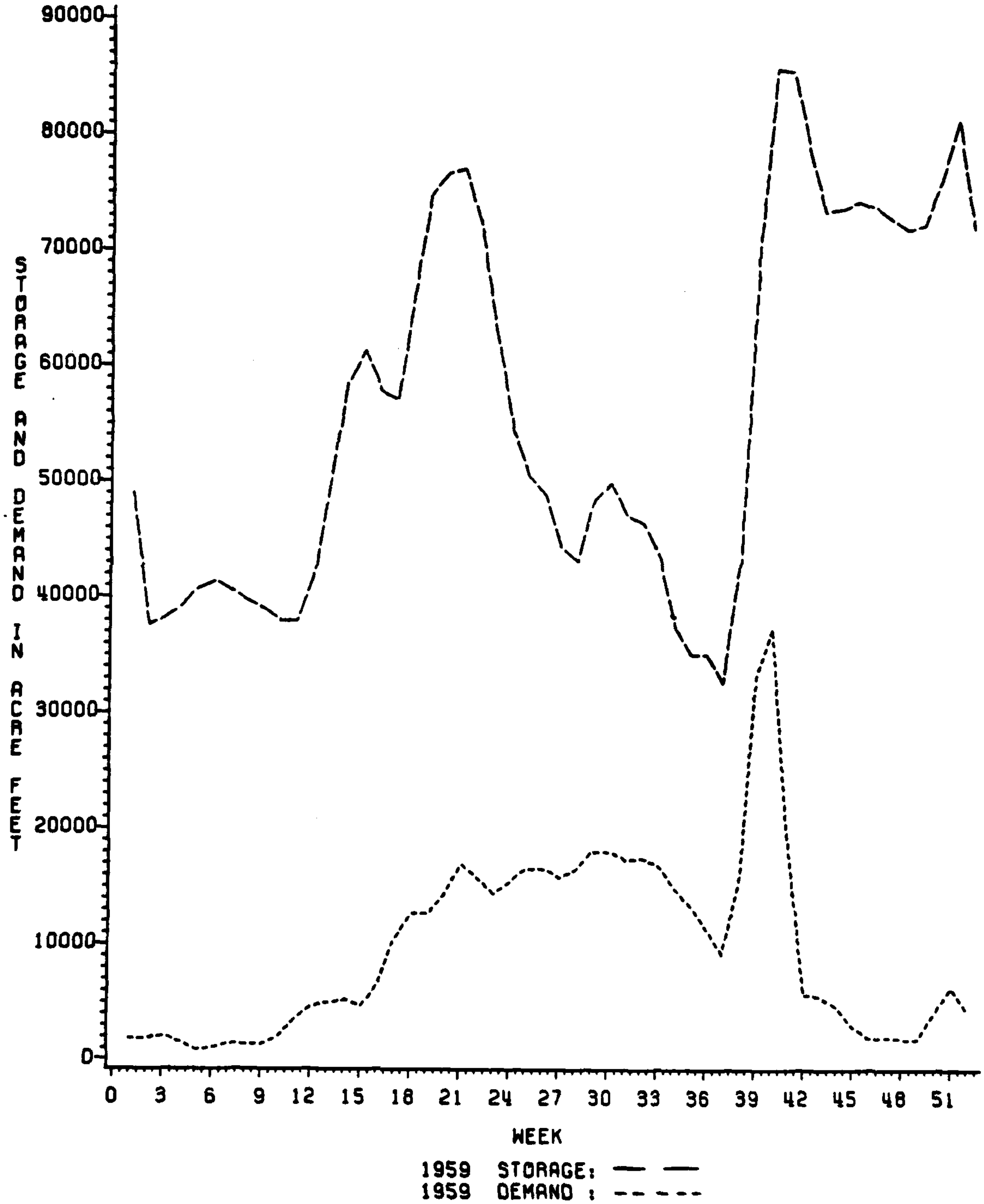


Figure 69. Storage and demand vs. time; 1959 weekly means for subbasin B13 of the North Canadian River; storage and demand in acre feet per week.

increase (week 15) and decrease (week 42) in the 1980 storage could conceivably be explained by heavy precipitation in the early spring, and lake releases (to Lake Overholser in Oklahoma City) in the fall (because of the very dry summer). In truth, these changes are due to missing lake contents for the first fifteen weeks and the last ten weeks of the year.

The early fall demand peak (Figure 71) is also the result of missing lake data. In 1959, a similar peak was caused because runoff from heavy precipitation was not correctly reflected as a change in lake contents. In 1980, there was not a heavy precipitation event. Rather, the peak is the result of the computed change in lake contents from 110,000 acre feet (week 42) to 0 (i.e., missing) in week 43. In both cases, the root cause of the incorrect demand peak was erroneous lake data.

Figure 72 (storage and demand for 1980) indicates a water deficit occurred. This is probably not true, because as we have seen, neither the demand peak (week 43) nor the storage drop (week 43) actually occurred.

Two points should be made from this case study. First, the more general point, is that care must be used when interpreting this, or indeed, any, large scale applied hydro-climatology research results. The second, and more specific point, is that the channel loss term, and consequently both storage and demand, is sensitive to erroneous data. This sensitivity is magnified in subbasins which contain lakes.

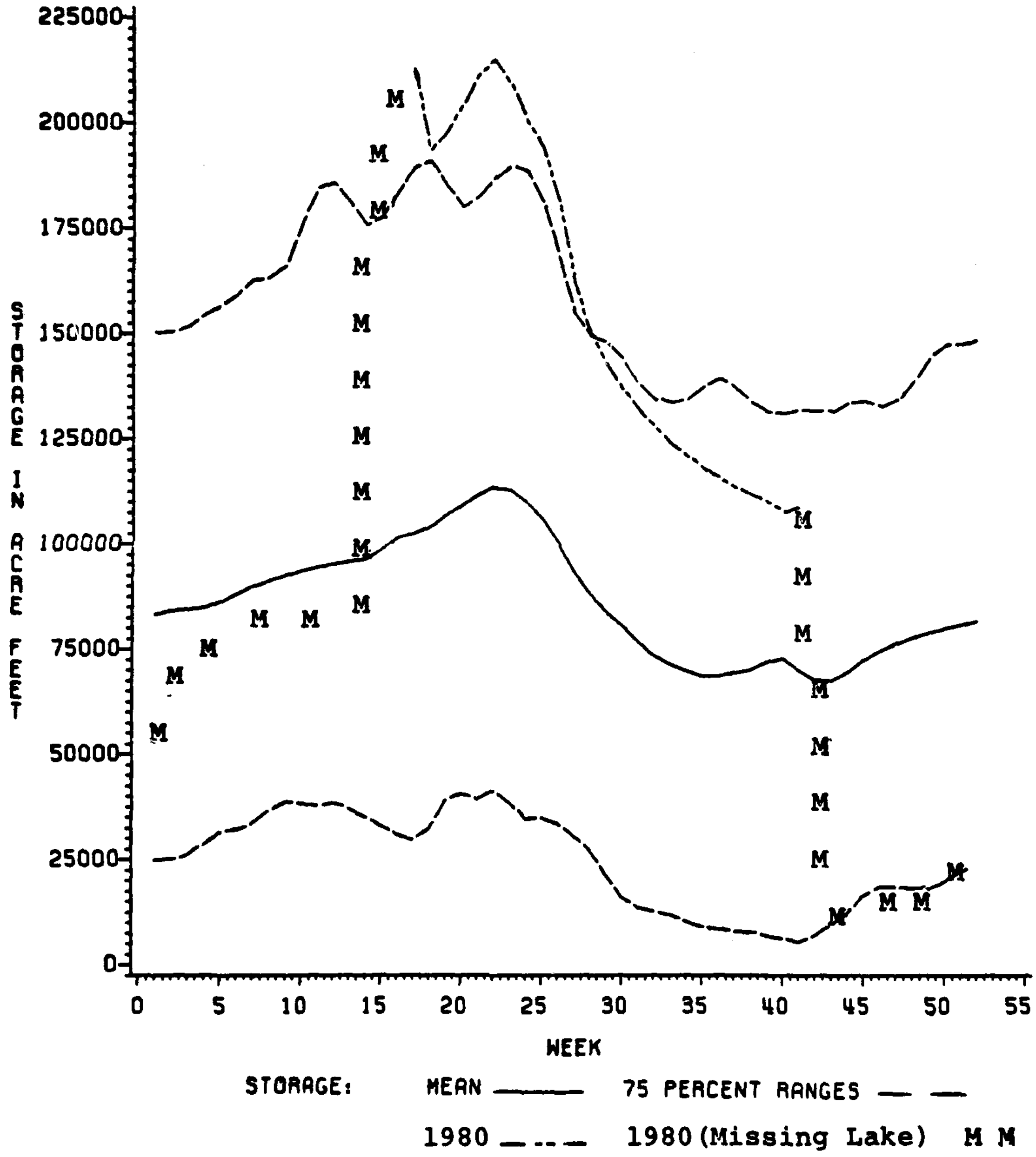


Figure 70. Storage vs. time; long-term weekly means, 75 percent ranges and 1980 weekly means for subbasin B13 of the North Canadian River, storage in average acre feet per week.

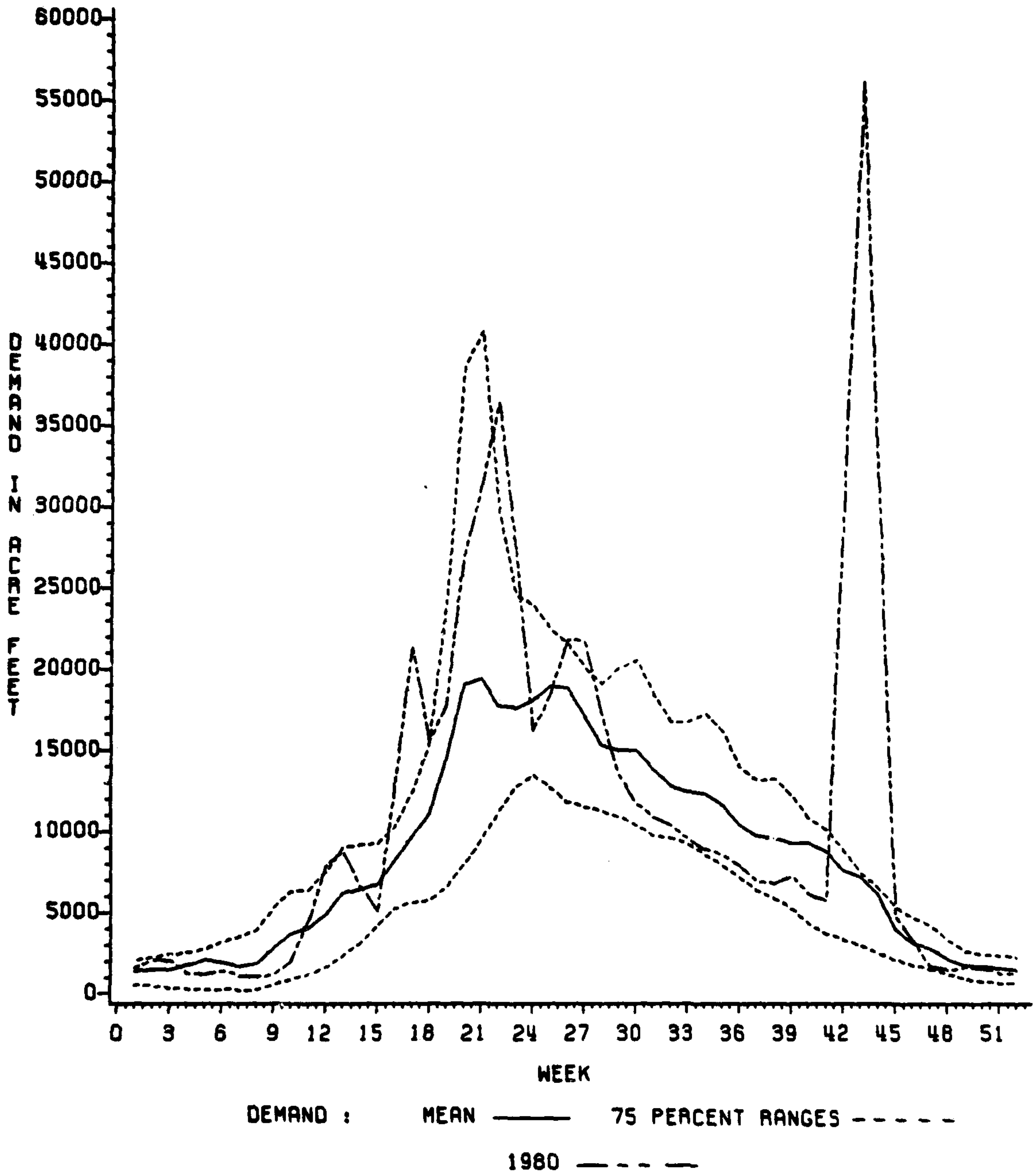


Figure 71. Demand vs. time; long-term weekly means, 75 percent ranges and 1980 weekly means for subbasin B13 of the North Canadian River; demand in acre feet per week.

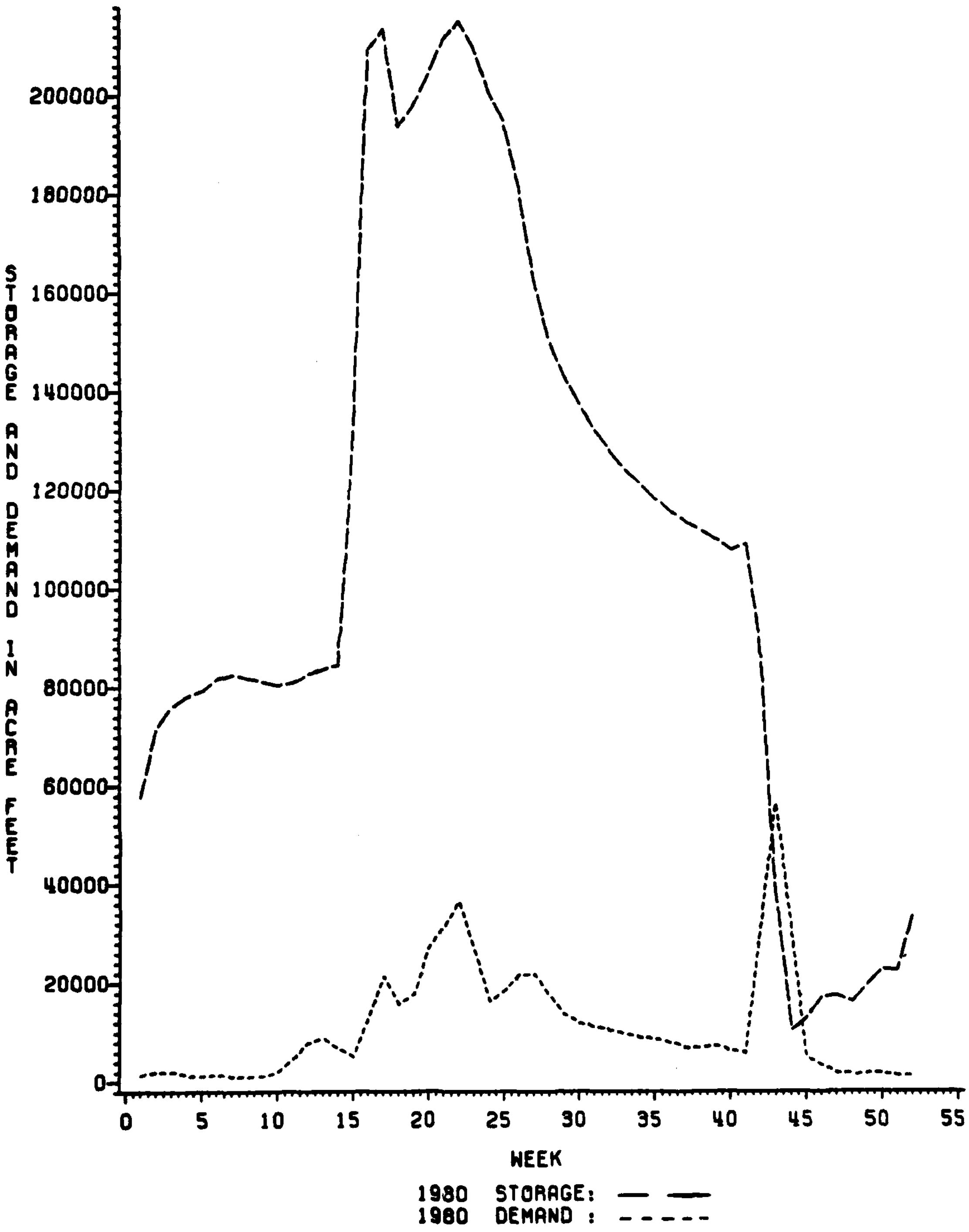


Figure 72. Storage and demand vs. time; 1980 weekly means for subbasin B13 of the North Canadian River ; storage and demand in acre feet per week.

5.6 Possible Applications

Although it is not the purpose of this thesis to investigate applications for information presented (such as storage-demand critical periods or frequencies of deficit) it is instructive to consider briefly some possible benefits and applications.

One example from agriculture is the trade-off between production of cattle and winter wheat. Eddy and Shannon (1975) set the stage for a decision theory problem this way:

> Many farmers in Oklahoma and Texas combine wheat and cattle activities by grazing cattle on growing winter wheat fields. When pastures again become green, they move the cattle to the pastures and allow the wheat to grow and produce grain. However, when rainfall is scant, wheat yields may be so poor that it becomes more economical to graze the wheat to the ground. The farmer/rancher cannot set prices for his cattle, but must take what the market offers at time of sale.

According to Nicks (1982, personal communication) the rancher must generally make a decision in early March whether or put cattle to pasture or send them to market. A major consideration is the availability of good pasture through the summer, which largely depends on water storage in soil moisture. Knowledge of the soil moisture climatology and a prediction for soil moisture through the summer (based, at least in part, on that climatology and the frequency of water deficit) would bear heavily on the farmer/rancher's decision.

Compounding the marketing and economic situation is the problem of wheat phenology. The two moisture critical times for winter wheat are when the head is forming and when it is filling out (E. J. Cooter, 1978). The wheat depends heavily on soil moisture storage in the fall and winter. We have seen that even in the wettest years, storage

decreases rapidly in the summer. A dry fall, however, does not allow for normal soil moisture recharge, and consequently, winter wheat may suffer. We have also seen (at least for the five driest years between 1951 and 1980), that dry years are caused primarily by very low late summer and fall precipitation. This is exactly the worst situation for winter wheat.

Beaver County, in the Oklahoma panhandle, ranked tenth in winter wheat production in 1979-1980 (Oklahoma Department of Agriculture, 1980). Earlier in this study (Section 5.4.1) we examined subbasin B11 of the North Canadian River, which encompasses most of Beaver County. There we saw that in one-third of the years studied a water deficit occurred (Table 6). The period of the deficit (beginning as early as mid-May) was not during the critical phenological period for wheat. However, it was during the time when summer pasture was critical for cattle.

In the decision theory problem that began this example, the states of nature include whether or not the spring was wet or dry. From this study we can determine how wet or dry the spring was using the current and long-term mean storage. The rainfall forecasts required for the decision theory problem could be stated in terms of probability of water deficit. We see the problem, then, in terms of water storage and deficit, which are more meaningful because precipitation is only indirectly available for plant growth.

Two words of caution are appropriate. First, the storage-demand critical periods and water deficits in this study do not take into account the phenological moisture demands of any particular crop.

Second, most winter wheat in Beaver County is on irrigated, rather than dry-land. With the depletion of the Ogallala aquifer, however, the importance of dry-land farming will increase. The information above could be used to examine the meteorologic and economic feasibility of such farming.

W. S. Cooter (1981) discussed two applications of input-output economic analysis; water resource planning and climatic impact assessment. Both areas could benefit from results of this and similar studies. Cooter demonstrated that water is a constraint to economic development in Oklahoma. Describing water resource planning he said:

> One can...compare the estimated requirements with the water supplies actually available. If the water required is dangerously close to, or actually exceeds, the water available, then the regional economy could not likely sustain the associated levels of economic sales and purchases.

Cooter gives water use coefficients that allow one to convert acre feet of water into dollars in the regional economy. The storage-demand and water available climatologies developed in this thesis could be used in such an input-output model.

In discussing climate impact assessment, Cooter postulated "...a crop impact model that relates changes in crop sector production... to changes in soil moisture for a critical period, e.g., a critical week or month during the growing season." The crop model could translate changes in soil moisture into crop production and dollars. The critical periods for potential water deficit, as well as the probabilities of deficit, in this thesis are directly applicable in such studies.

Reservoirs, as Canton Lake in subbasin B13 and Altus Lake in subbasin B23, can serve as decision points for water planners. Altus

Lake has a small committment for municipal supply to the City of Altus, but the bulk of the reservoir contents are allocated to irrigation. We can see an interesting decision problem, for instance, by looking at the consumptive water use and net irrigation requirements for cotton and winter wheat (Table 9).

Table 9. Monthly consumptive water use and net dry year irrigation requirements for cotton and winter wheat (in inches); for Altus, OK, (from USDA, 1981a).

Month	Winter Wheat Consumptive Use	Net Irrigation	Cotton Consumptive Use	Net Irrigation
October	1.92*			
November	2.01*			**
December	.80			
January	.80			
February	1.90			
March	3.37	1.59		
April	4.26	3.01		
May	1.94	.40	0.77*	
June	0 **		2.83	
July	**		6.66	5.25
August			8.89	7.46
September			5.73	4.06
October			2.67	0 **

* Indicates planting month
** Indicates harvesting month

We see that irrigation requirements for winter wheat are in March, April and May, while for cotton they are in July, August and September. If the area experiences a dry spring (resulting in below normal water storage) many potential problems develop. Do you irrigate

wheat, that is already in the ground, to ensure full head development? What, then, if normal May precipitation does not occur, and storage (soil moisture and lake contents) is further depleted? Do you plant cotton in May (and hope) knowing the large net irrigation requirements in July, August and September? On the other hand, back in March, should you withhold irrigation from wheat and conserve storage for later needs (i.e., cotton)? We saw (Section 5.4.2) the storage-demand and deficit climatology for subbasin B23. Figure 52 showed that potential water deficits were possible from late April to mid-November. Further, Table 8 demonstrated that deficits did, in fact, occur in almost 50 percent of the years studied. It would appear this type of information could have substantial beneficial use to irrigation planning and cropping strategy in that area.

For a last example we look at the area of weather modification (i.e., precipitation agumentation). Without addressing the pros and cons of how well weather modification will work (from the meteorological or statistical viewpoints), there is evidence of its potential agricultural benefit. For instance, Bart, et al. (1979) performed an interesting study of possible weather modification impact, showing resulting changes in cropping strategies and associated economic benefit in nearby Kansas.

Results from this thesis could be useful in planning a weather modification project. For example, should weather modification be planned in the spring, when the soil moisture table normally is already high? We have seen that a larger percentage of May rainfall will become runoff, than say, July rainfall. Increasing spring rains would

normally be good for increasing reservoir and stock pond levels, but not for increasing soil moisture. On the other hand, a greater percentage of summer rainfall (compared to spring) is used to directly satisfy evapotranspiration demand and recharge soil moisture. The storage-demand critical periods and deficit climatologies could also provide information on where and when additional water supply was needed.

5.7 Research Limitations and Recommendations for Further Study

This research, as all research must be, was limited by design. Numerous assumptions were made either to simplify complex portions of the problem or in order to quantify areas where little or no data were available. For different reasons, such as the different order of magnitude of terms, some assumptions appear to have had little affect on the results of the study, while others had serious impacts. For example, simple arithmetic averaging of a parameter to obtain a single basin-wide figure appears totally consistent with the scale of the study. On the other hand, accounting for all groundwater interaction with the residual channel loss term undoubtedly vastly oversimplified a very complex problem. However, this was done with full prior knowledge and dictated by the scale and emphasis of the study, as well as the background of the researcher.

Further research should follow two basic thrusts. First, each area in which simplifying assumptions were made is ripe for improvement. In several of those areas, such as runoff modeling and groundwater dynamics, sophisticated models already exist. Merging these models into a study of this ilk without losing sight of the original problem is no

small task in integration. It is also an area that begs for a multi-disciplinary attack.

The second direction for further study is in the area of applicability. Several very brief examples of the possible utility of information from this study were given. However, they were sketchy and non-rigorous because that was not the purpose of this thesis. Any future studies must address explicitly the benefit of the information to customers, be they farmers, water planners or cloud scientists.

CHAPTER VI

SUMMARY AND CONCLUSIONS

In this thesis hydrologic and meteorologic data were gathered from several sources, missing data values were filled in through interpolation, the data were averaged over space and time and a set of basic variables was derived. Using these basic variables, additional variables were calculated, including channel loss, storage, demand and delta: the direct contribution of rainfall to satisfying evapotranspiration demands. The characteristics, physical interpretation and interrelationships among variables were discussed in detail. For example, we saw in Figure 44 that unless storage in soil moisture and reservoirs is sufficient by late May there is potential for water deficit during the summer. This is because, after the late spring rainfall peak, the majority of rainfall is used to satisfy evapotranspiration demands directly (delta), rather than for soil moisture recharge or runoff.

Storage and demand values were analyzed and potential deficit periods were identified between where their 75 percent empirical envelopes intersected. Joint frequency tables for the critical weeks illustrated how often actual deficits occurred; as frequently as 14 years out of 30 for one subbasin.

Then case studies for two subbasins for a dry year, a wet year and a mixed year were presented. In one case the sensitivity of storage

and demand calculations to erroneous or missing data was demonstrated. The second case was for subbasin B21. In the long-term we found (see joint frequency table in Appendix C) that in one of thirty years we could expect a deficit during the mid-excess period. However, in over a third of the years (13 of 30) we could expect a deficit during the mid-deficit period. In a dry year, 1956, we saw that an actual deficit did occur; for almost six months (June until November). During the wet year, 1959, no deficit occurred, at any time. Finally, despite 1980 beginning as a very wet year, the lack of summer precipitation and record hot weather resulted in a total of four weeks of deficit during the summer. This case study illustrated that the long-term potential for deficit (shown in the storage-demand curves and the joint frequency tables) could be examined for individual years, and actual deficits verified.

Finally, four examples of possible applications of the agro-hydro-meteorological climatologies developed in this study were presented. Two agricultural examples were given. The trade-off between winter wheat and cattle production in Beaver County, Oklahoma was discussed in the context of a decision theory problem for dryland farming. Secondly, it was suggested that the study results would be useful in the reservoir management and irrigation scheduling decision process for winter wheat and cotton crops in the Altus-Lugert Irrigation District in southwestern Oklahoma. Then, an economic input-output model used for water resource planning and climate impact assessment was discussed. Study results could be useful as input to this model which can translate acre feet of available water into dollars in the regional economy. Lastly, the utility of storage, demand and deficit climatologies developed in this

study were deemed to be of value in the planning, implementation and evaluation of a weather modification program.

BIBLIOGRAPHY

Bark, L. Dean, Orlan H. Buller and Richard L. Vanderlip, 1979: Cloud Seeding: Potential Benefits for Kansas Agriculture. Bulletin 628, Kansas State University Agricultural Experiment Station, Manhattan, KS.

Bollman, F. H. and M. A. Merritt, 1978: "Community Response to Change in Residential Water Use," supporting materials for tape numbers 293, 294, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

Bureau of Economic Geology, 1969: Geologic Atlas of Texas; Amarillo Sheet. University of Texas, Austin, TX.

Cooter, Ellen J., 1978: Climate/Yield Relationships for Kansas Winter Wheat. MS Thesis, The University of Oklahoma, Norman, OK.

_________, 1981: "The Impact of Climate on Rural Water Management in Oklahoma," in The Economic Impact of Climate on Water Management in Oklahoma, Vol. VI, Oklahoma Climatological Survey, Norman, OK, pp. 37-56.

Cooter, William S., 1981: "Economic Models for Water Resource and Climate Impact Applications," in The Economic Impact of Climate on Water Management in Oklahoma, Vol. VI, Oklahoma Climatological Survey, Norman, OK, pp. 57-81.

Curry, Billy R., 1973: Meteorological Droughts and Wet Spells in Oklahoma. The University of Oklahoma, Norman, OK, 63 pp.

Eddy, Amos and Jack D. Shannon, 1975: Weather Related Decision Making. Oklahoma Climatological Survey, Norman, OK, 272 pp.

_________, and Ellen Cooter, 1978: A Drought Probability Model for the U.S.A. Northern Plains. Oklahoma Climatological Survey, Norman, OK, 83 pp.

_________, 1982: "The Economic Impact of Climate on Water Resources Management," paper presented at the American Water Resources Association International Symposium, June 1982, Denver, CO.

Hill, Jerry D., 1974: "The Use of a 2-Layer Model to Estimate Soil Moisture Conditions in Kentucky," Monthly Weather Review, Vol. 102, pp. 726-730.

Huschke, R. E., ed., 1959: Glossary of Meteorology. American Meteorological Society, Boston, MA, 638 pp.

Jensen, D. T., 1978, "Vulnerability of Water Supply Systems to Drought," unpublished Ph.D. dissertation, Utah State University, Logan, UT, 168 pp.

Knisel, W. G. and A. D. Nicks, 1980: "CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems," USDA Conservation Research Report Number 26, Washington, D.C., GPO.

Linsley, Ray K., Jr., Max A. Kohler and Joseph L. H. Paulus, 1975: Hydrology for Engineers. 2nd ed. McGraw-Hill, New York, 481 pp.

Major, Jack, 1963: "A Climatic Index to Vascular Plant Activity," Ecology, Vol. 44, pp. 485-498.

Mather, John R., 1974: Climatology: Fundamentals and Applications. McGraw-Hill, New York, 412 pp.

_________, 1978: The Climatic Water Balance in Environmental Analysis. D. C. Heath and Co., Lexington, MA, 239 pp.

Oklahoma Geological Survey (OGS), 1975: Hydrologic Atlas #4. Reconnaissance of the Water Resources of the Oklahoma City Quadrangle, Central Oklahoma. By Roy H. Bingham and Robert L. Moore, The University of Oklahoma, Norman, OK.

_________, 1976: Hydrologic Atlas #5. Reconnaissance of the Water Resources of the Clinton Quadrangle, West-Central Oklahoma. By Jerry E. Carr and DeRoy L. Bergman, The University of Oklahoma, Norman, OK.

_________, 1977: Hydrologic Atlas #6. Reconnaissance of the Water Resources of the Lawton Quadrangle, Southwestern Oklahoma. By John S. Havens, The University of Oklahoma, Norman, OK.

_________, 1980: Hydrologic Atlas #8. Reconnaissance of the Water Resources of the Woodward Quadrangle, Northwestern Oklahoma. By Robert B. Morton, The University of Oklahoma, Norman, OK.

Oklahoma Water Resources Board (OWRB), 1976: Oklahoma's Water Atlas, 1976. OWRB Pub. 76, Oklahoma City, OK.

_________, 1980: Oklahoma Comprehensive Water Plan. OWRB Pub. 94, Oklahoma City, OK.

Palmer, Wayne C., 1965: Meteorological Drought. U.S. Department of Commerce, Weather Bureau Research Paper No. 45.

_________, 1968: "Keeping Track of Crop Moisture Conditions Nationwide: The New Crop Moisture Index," Weatherwise, Vol. 21, No. 4, pp. 156-161.

Pflaum, John C. and Amos Eddy, 1982: A Course of Action for Oklahoma. Vol. 3, Operational Weather Modification, Oklahoma Climatological Survey, Norman, OK, 18 pp.

Rosenberg, Norman J., ed., 1979: Drought in the Great Plains: Research on Impacts and Strategies. Water Resources Publication, Littleton, CO, 225 pp.

Thornthwaite, C. W., 1948: "An Approach Toward a Rational Classification of Climate," Geograph Review, Vol. 38, pp. 55-94.

U.S. Department of Agriculture (USDA), 1977: Climatic Atlas of the United States. USDA/EDIS, Asheville, NC.

_________, 1981a: Oklahoma Irrigation Guide. USDA, Soil Conservation Service, Stillwater, OK, unnumbered.

_________, 1981b: Irrigation Scheduling. 4th ed. Cooperative Extension Service, Agricultural Engineering Department, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, NE.

U.S. Geological Survey (USGS), 1952: Water Loss Investigation: Lake Hefner Studies Report. Prof. paper 269.

_________, 1974: WATSTORE User's Guide. Open File Report 75-426.

_________, 1981: Water Resources Data for Oklahoma, Water Year 1977, Arkansas River Basin. Water Data Report OK-79-1, USGS Water Resources Division, Oklahoma City, OK.

_________, 1981: Water Resources Data for Oklahoma, Water Year 1979, Red River Basin. Water Data Report OK-79-2, USGS Water Resources Division, Oklahoma City, OK.

Viessman, Warren, Jr., John W. Knapp, Gary L. Lewis and Terrence E. Harbaugh, 1977: Introduction to Hydrology. 2nd ed. Harper and Row, New York, 704 pp.

APPENDIX A

HYDROLOGIC ACCOUNTING SYSTEM

According to Palmer (1965), "The water balance or hydrologic accounting approach to climatic analysis allows one to compute a reasonably realistic picture of the time distribution of moisture excesses and deficiencies."

The simple hydrologic accounting system used in this thesis was developed based on a more humid climate than that in western Oklahoma (Thornthwaite, 1948). However, for over thirty years it has been widely used (e.g., Major, 1965; Palmer, 1965, 1968; Eddy and Cooter, 1978) in a broad range of climatic regimes, because it requires only temperature data as input. The ability of the simple model to accurately represent the state of nature varies with the climate. For example, in eastern Nebraska, a similar model, based only on temperature, was found sufficiently accurate for irrigation scheduling (USDA, 1981b). However, in the more arid western part of Nebraska (similar to western Oklahoma) this model underestimated the potential evapotranspiration (PET). In fact, even models using temperature and solar radiation "underestimated water use under dry, windy conditions" (USDA, 1981b). In Nebraska, using modified Penman equations, with temperature, humidity, solar radiation and wind as inputs, the calculated PET was more accurate. In many areas, such as western Oklahoma, wind and humidity data simply are not available.

For that reason, the simple Thornthwaite hydrologic accounting system was used. It is briefly described below. For a full discussion see Palmer (1965).

The accounting system is driven by potential evapotranspiration (PET), which is the amount of evapotranspiration that would occur if there were no moisture constraints. However, because PET is a complicated process requiring a specialized observational network to calculate it directly, it is often approximated using precipitation and temperature data. Thornthwaite's (1948) empirical approximation, used by Palmer, is followed in this study. Thornthwaite's relationship is

$$e = 1.6\ (10T\ /\ I)^{a}$$

where e is unadjusted potential evapotranspiration (mm), T is monthly temperature (C) and I is an annual heat index, computed from the sum of the monthly heat index values (dimensionless). I is computed as follows

$$I = \sum_{i=1}^{12} (Ti\ /\ 5)^{1.514}$$

where Ti is long-term monthly temperature (C), and a is a nonlinear function of the heat index calculated from the following equation.

$$a = 6.75 \times 10^{-7} I^{3} - 7.71 \times 10^{-5} I^{2} + 1.79 \times 10^{-2} I + 0.49$$

The variables used in the water budget include

P = precipitation,

SS = surface soil moisture (1" available water capacity (AWC),

SU = underlaying layer soil moisture (dependent on soil type),

ET = actual evapotranspiration,

PET = potential evapotranspiration,

R = actual recharge of the soil moisture, and

RO = runoff.

The accounting system, which used weekly values, followed this logic.

a. The PET demand is first satisfied directly by precipitation (called delta in this thesis). Precipitation (P) in excess of PET is available for soil moisture recharge (R) and then runoff (RO).

b. If PET is not completely satisfied by P, then water is withdrawn from the soil. First, the surface soil layer (SS), with 1" of available water capacity (AWC) is depleted on a one for one basis. That is, if, after P, PET requires one-half inch, then SS gives up one-half inch. If there still remains PET demand the underlying soil layer (SU) begins to be depleted. The maximum water content of this layer is 1" less than the total AWC for the soil type. For this study the AWC values were 6" or 7". However, this moisture is available on a pro-rated basis, not one for one, as the SS layer. For example, if PET is 5", and P satisfies 1" and SS satisfies 1", there is 3" of demand remaining. If the AWC is 7", then SU will satisfy PET at the rate of

$$\left(\frac{AC}{AWC}\right) * RD,$$

where AC is the available water capacity of the underlying soil layer, AWC is total available capacity and RD is the remaining demand. PET can be completely satisfied (i.e., ET=PET) only if there is enough P and SS. If SU is used, actual ET will be less than PET.

c. If P is greater than PET demand, then the soil moisture is recharged. The actual recharge (R) is first to the SS layer, then to SU. However, whereas withdrawal is prorated from SU, recharge is not. If 4"

are available for R, up to 1" goes to SS; and the remaining, if required, goes to SU.

d. The only time RO will occur in this model is when the soil layer is full (i.e., SS + SU = AWC).

e. Other variables such as loss, potential loss and potential recharge are useful for bookkeeping, but are not essential to the model logic, so they are not explained here.

In addition to the problem of estimating PET as a function of temperature alone, as discussed earlier in this appendix, another basic assumption in the simple hydrologic accounting model used merits comment. The model does not allow any runoff until evapotranspiration demands and soil moisture recharge demands have been met. As mentioned in section 4.4.3, this is obviously an approximation of the truth. Since western Oklahoma has periods of very heavy rain and little native vegetation to retard runoff, one might consider the effect of a model that allowed runoff to occur before ET and SM recharge demands were fully met, or in fact, before any ET and SM demands were met. A model that allowed more runoff would result (in this thesis) in less soil moisture recharge and thus lower the soil moisture curves in the text. It would also result in decreased evapotranspiration, because there would be less available moisture to give up. This presents one problem; namely, that in arid western Nebraska it was found that a simple (temperature only input) hydrologic budget <u>underestimated</u> evapotranspiration (USDA, 1981b). Yet, allowing more runoff in the model, further decreases the amount of evapotranspiration possible. Increasing the percentage of runoff in the model would also have the effect of increasing the magnitude of the channel loss

term; the runoff component of Equation (4.6) would be large and the other terms would not change.

Testing whether the runoff is correctly apportioned is no mean task. As a first step, a very simplistic and non-rigorous method would be to compare the ratio of net stream discharge (SO-SI) to precipitation. If a consistent runoff to precipitation ratio were found, then one could redefine the model so that the proportion of precipitation went directly to runoff before being used to satisfy ET or SM recharge. Such a calculation was performed for subbasin B14 of the North Canadian River for 1980. Two ratios were calculated; net stream discharge to precipitation in the same week, and a time-lagged ratio (net stream discharge for the following week to precipitation in the current week). The result was anything but a consistent ratio, or even a consistent pattern in the ratios. For the non-time-lagged ratio, the range was 34.8384 to -0.0099, with a mean value of 0.7995. Without one very large value (34.8384), the range was 4.5090 to -0.0099, with a mean value of 0.1302. This is probably more realistic. For the time-lagged ratio the range was 2.8829 to -4.2798, with a mean value of 0.1564. In the mean, with one value removed, about 15 percent of precipitation becomes runoff in both calculations. What is very troubling, however, is the large number of negative ratios (19 of 34 non-time-lagged; 13 of 36 time-lagged). The negative ratios indicate that precipitation not only did not produce runoff (increased net stream discharge), but rather a third to a half of the time, precipitation resulted in decreased net stream discharge. Of course, that is a nonsensical result. The negative net stream discharge (SO-SI) must result from losses from the stream channel and evaporation.

Conversely, the ratios greater than one are probably the result of basin precipitation that was not measured by the reporting stations. While the above test did not yield consistent results, it would still appear that in some cases it is important to consider runoff occurring before ET and SM recharge demands are fully met. One aspect of future work should be to examine in greater detail the relationship of precipitation to runoff (also; ET and SM recharge).

APPENDIX B

JULIAN WEEK CALENDAR

Julian Week	Month/ Date	Julian Week	Month/ Date
1	Jan 1-7	25	Jun 17-23
2	Jan 8-14	26	Jun 24-30
3	Jan 15-21	27	Jul 1-7
4	Jan 22-28	28	Jul 8-14
5	Jan 29 - Feb 4	29	Jul 15-21
6	Feb 5-11	30	Jul 22-28
7	Feb 12-18	31	Jul 29 - Aug 4
8	Feb 19-25	32	Aug 5-11
9	Feb 26 - Mar 3	33	Aug 12-18
10	Mar 4-10	34	Aug 19-25
11	Mar 11-17	35	Aug 26 - Sep 1
12	Mar 18-24	36	Sep 2-8
13	Mar 25-31	37	Sep 9-15
14	Apr 1-7	38	Sep 16-22
15	Apr 8-14	39	Sep 23-29
16	Apr 15-21	40	Sep 30 - Oct 6
17	Apr 22-28	41	Oct 7-13
18	Apr 29 - May 5	42	Oct 14-20
19	May 6-12	43	Oct 21-27
20	May 13-19	44	Oct 28 - Nov 3
21	May 20-26	45	Nov 4-10
22	May 27 - Jun 2	46	Nov 11-17
23	Jun 3-9	47	Nov 18-24
24	Jun 10-16	48	Nov 25 - Dec 1

Julian Week	Month/ Date	Julian Week	Month/ Date
49	Dec 2-8	51	Dec 16-22
50	Dec 9-15	52	Dec 23-31

NOTE: Based on a leap year; week 52 has 9 days.

APPENDIX C

TIME SERIES, HISTOGRAMS AND TABLES FOR ALL BASINS

This appendix contains a complete set of time series graphs for all the variables discussed in the body of the text. Additionally, percentage frequency histograms and joint frequency tables for storage and demand for the mid-excess and mid-deficit periods are included. The data are arranged by subbasin, B11-B24. For each subbasin the data are presented in the following sequence.

1st page: weekly mean time series for precipitation, runoff, soil moisture and evapotranspiration.

2nd page: weekly mean time series for stream inflow, stream outflow, stream contents and stream evaporation term.

3rd page: weekly mean time series for channel loss, storage and demand overlayed and storage and demand individually.

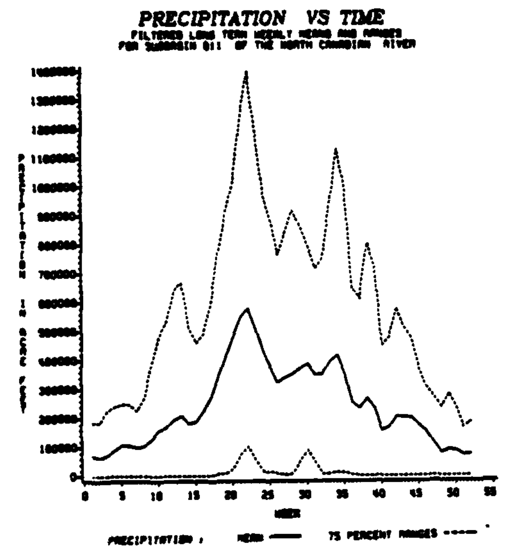
4th page: joint frequency tables for storage and demand for the mid-excess and mid-deficit periods and percentage frequency histograms for storage and demand for the mid-excess and mid-deficit periods.

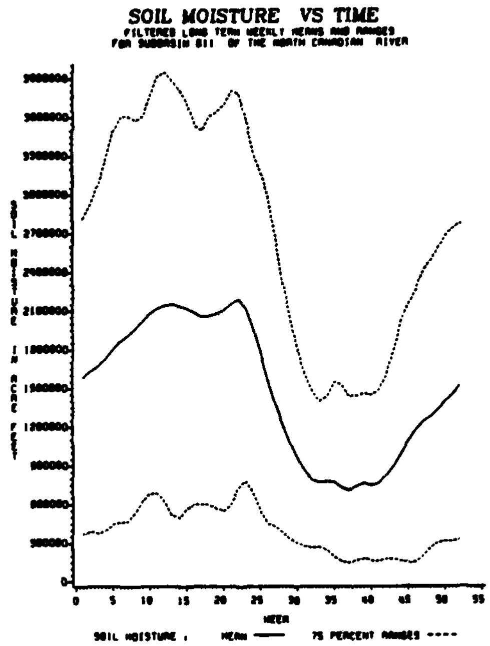
5th page: weekly mean time series for delta, evapotranspiration and potential evapotranspiration and for precipitation, runoff, recharge.

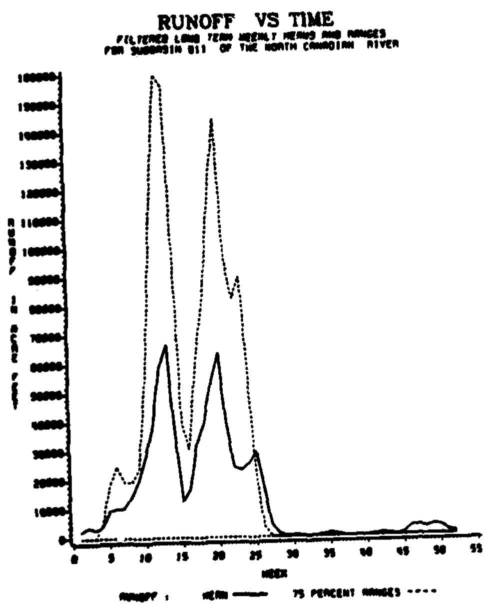
6th page: weekly mean time series for 1956 storage and demand overlayed, long-term storage, ranges and 1956 storage and long-term demand, ranges and 1956 demand overlayed.

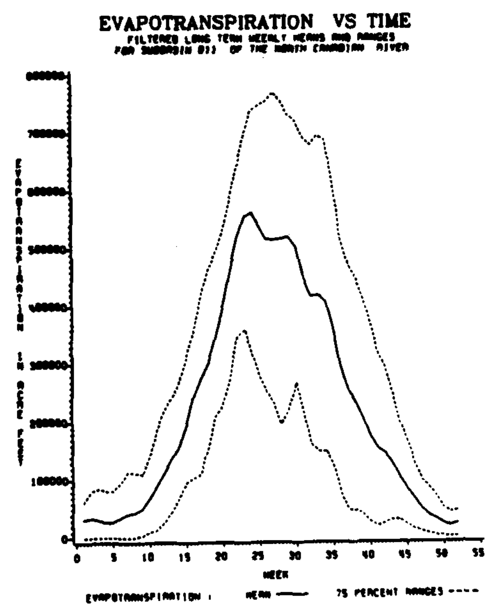
7th page: weekly mean time series for 1959 storage and demand overlayed, long-term storage, ranges and 1959 storage overlayed, and long-term demand, ranges and 1959 demand overlayed.

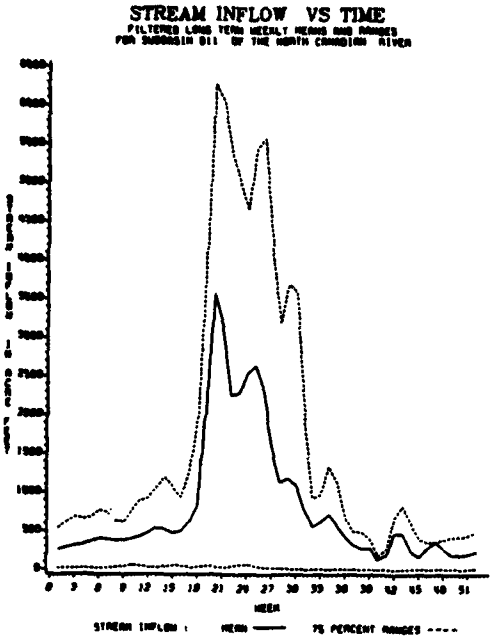
8th page: weekly mean time series for 1980 storage and demand overlayed, long-term storage, ranges and 1980 storage overlayed, and long-term demand, ranges and 1980 demand overlayed.

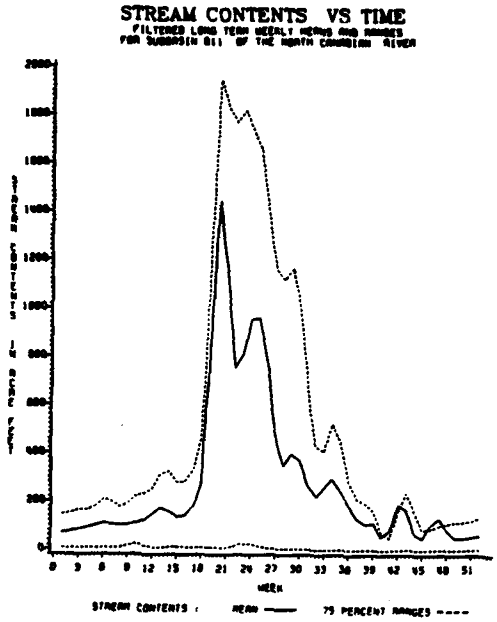

PRECIPITATION VS TIME
PRECIPITATION : MEAN —— 75 PERCENT RANGES ----
WEEK

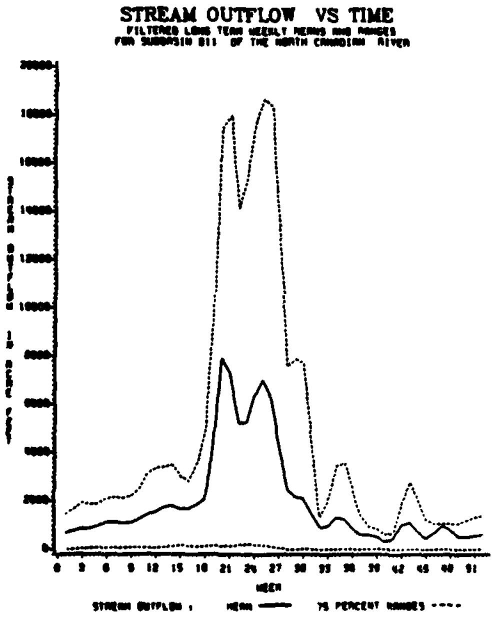

SOIL MOISTURE VS TIME
SOIL MOISTURE : MEAN —— 75 PERCENT RANGES ----
WEEK

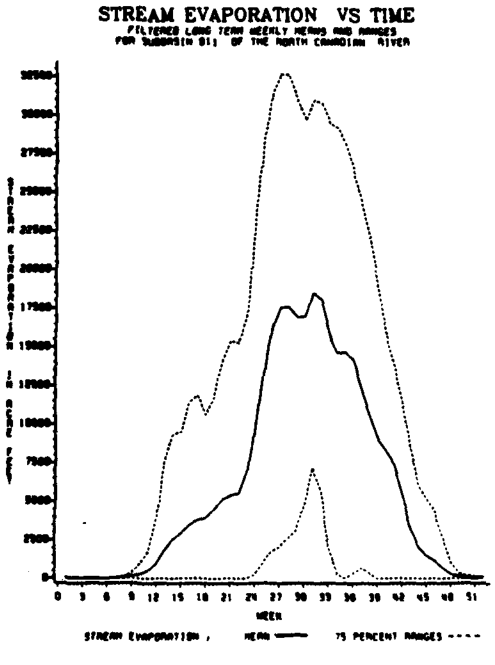

RUNOFF VS TIME
RUNOFF : MEAN —— 75 PERCENT RANGES ----
WEEK

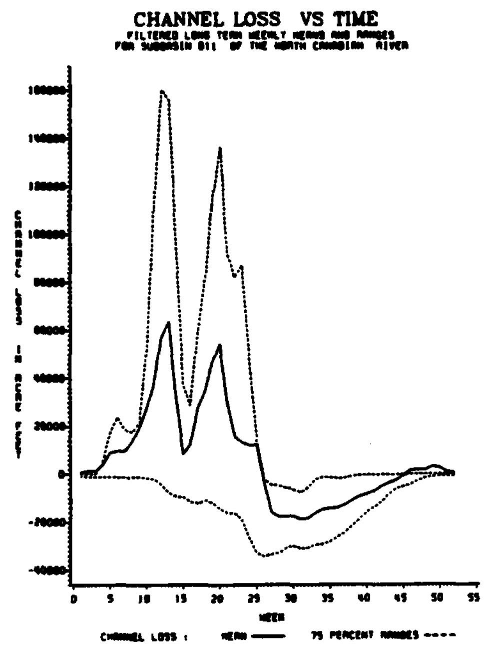

EVAPOTRANSPIRATION VS TIME
EVAPOTRANSPIRATION : MEAN —— 75 PERCENT RANGES ----
WEEK

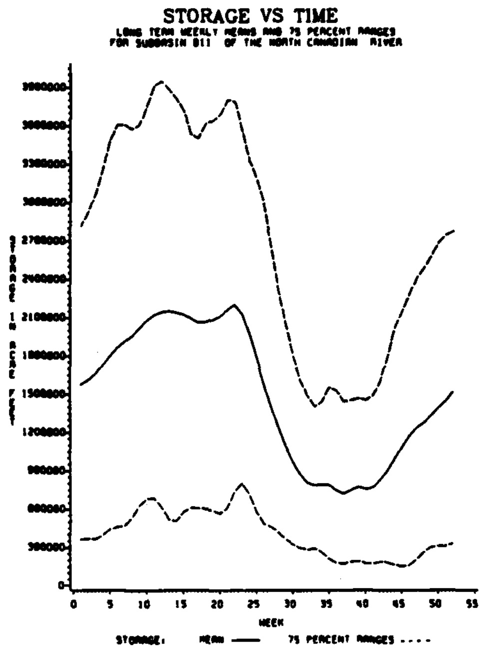

STREAM INFLOW VS TIME

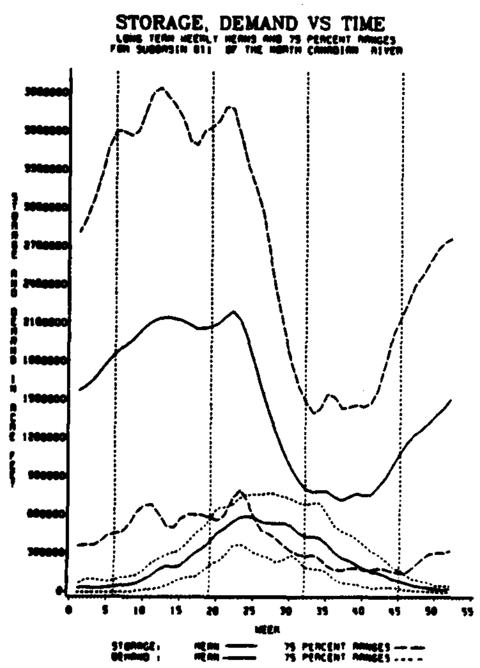

STREAM CONTENTS VS TIME

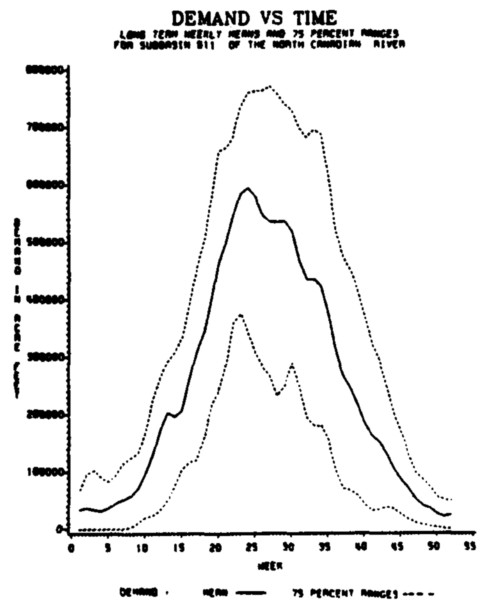

STREAM OUTFLOW VS TIME


STREAM EVAPORATION VS TIME

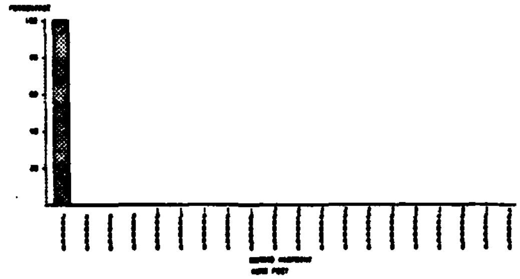

CHANNEL LOSS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
WEEK
CHANNEL LOSS : MEAN —— 75 PERCENT RANGES ----


STORAGE VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN —— 75 PERCENT RANGES ----


STORAGE, DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN —— 75 PERCENT RANGES ----
DEMAND : MEAN —— 75 PERCENT RANGES ----


DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND : MEAN —— 75 PERCENT RANGES ----

FREQUENCY OF DEMAND FOR WEEK 6



FREQUENCY OF STORAGE FOR WEEK 6

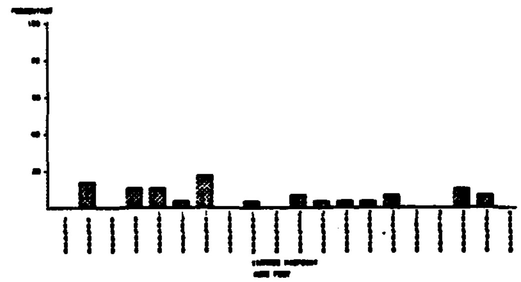


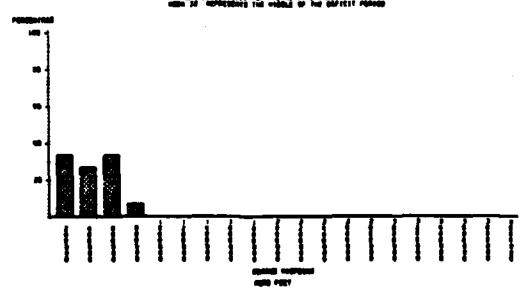
Table Joint frequency table for subbasin B11, week 6 (mid-surplus period).

0	0	0	5	2	0	5	1	D
0	0	0	1	0	1	1	10	E
0	0	0	5	2	2	5	45	M
0	0	0	6	4	2	6	1850	A
0	0	0	0	0	0	0	3600	N
0	0	0	0	0	0	0		D
0	0	0	17	8	5	30		
1	10	45	1850	3600				

STORAGE

Storage and demand in thousands of acre feet.

FREQUENCY OF DEMAND FOR WEEK 32



FREQUENCY OF STORAGE FOR WEEK 32

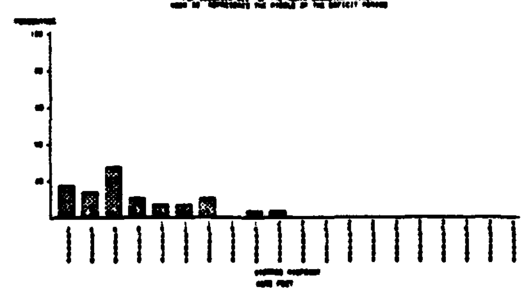


Table Joint frequency table for subbasin B11, week 32 (mid-deficit period).

1	1	3	0	0	0	5	200	D
0	0	3	2	0	0	5	300	E
0	3	6	0	0	1	10	700	M
0	0	0	0	1	1	2	800	A
0	0	0	0	0	0	0	1500	N
0	0	0	0	0	0	0		D
1	4	12	2	9	2	30		
200	300	700	800	1500				

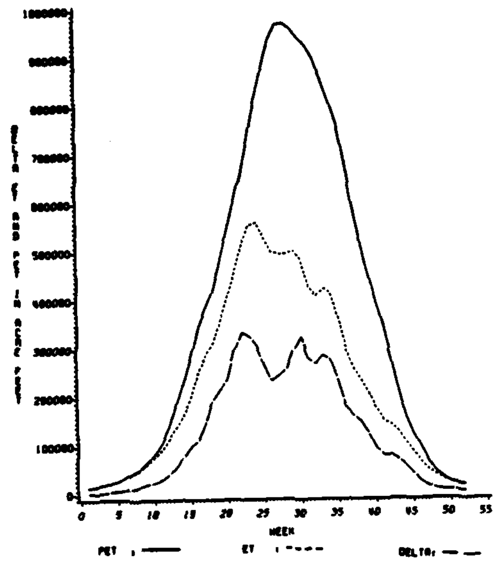
STORAGE

Storage and demand in thousands of acre feet.

DELTA, ET AND PET VS TIME

LONG TERM WEEKLY MEANS

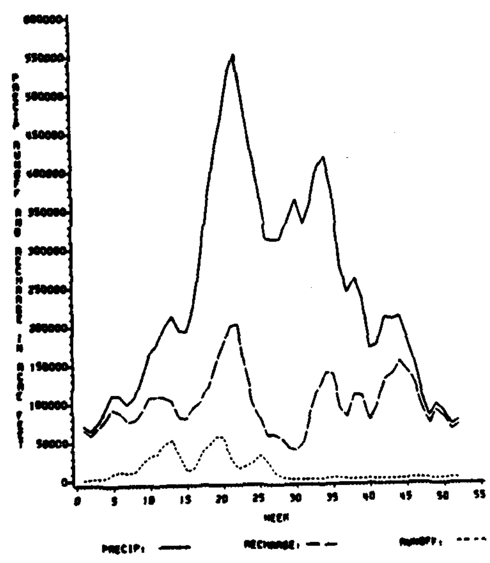
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER



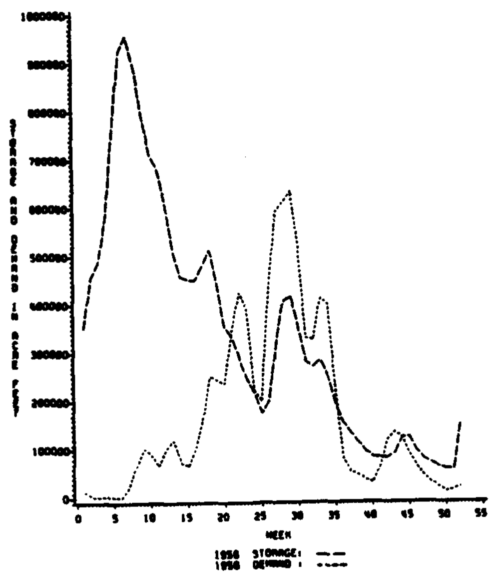
PRECIP, RUNOFF AND RECHARGE VS TIME

LONG TERM WEEKLY MEANS

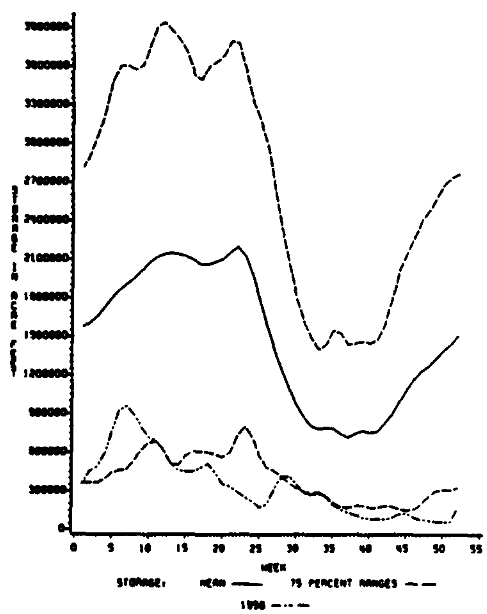
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER



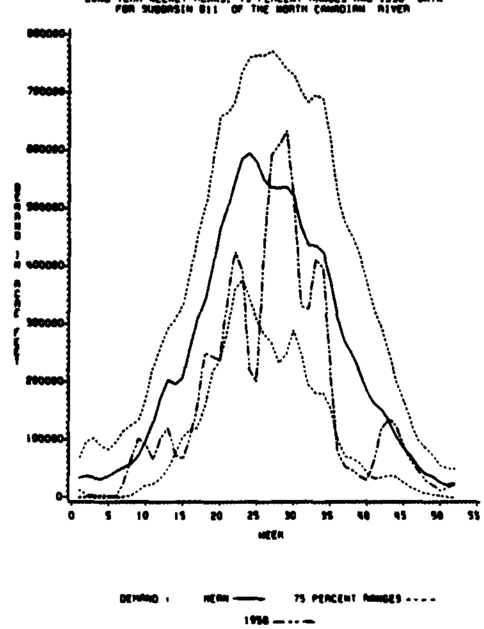
STORAGE, DEMAND VS TIME
1956 DATA ONLY
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER



STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1956 DATA
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER

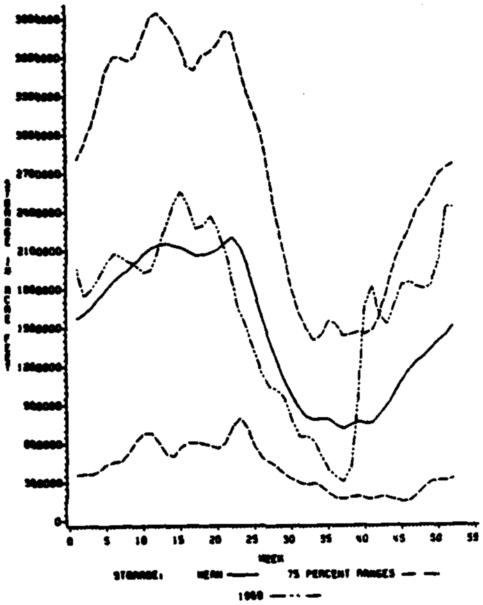


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1956 DATA
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER



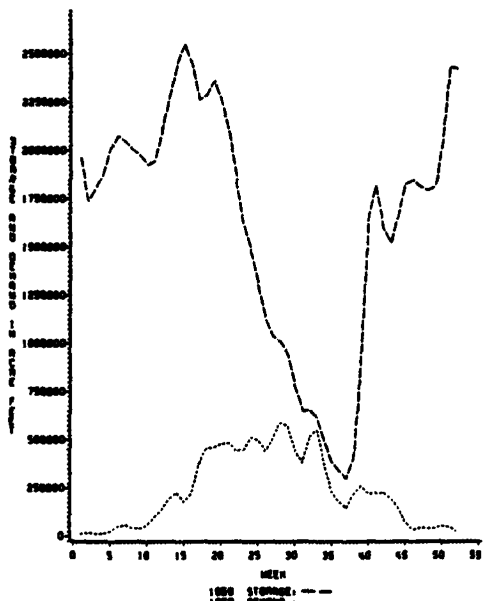
STORAGE VS TIME

LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1950 DATA
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER



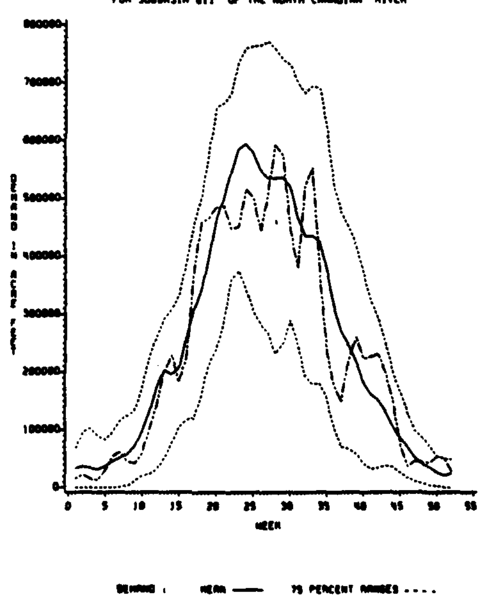
STORAGE, DEMAND VS TIME

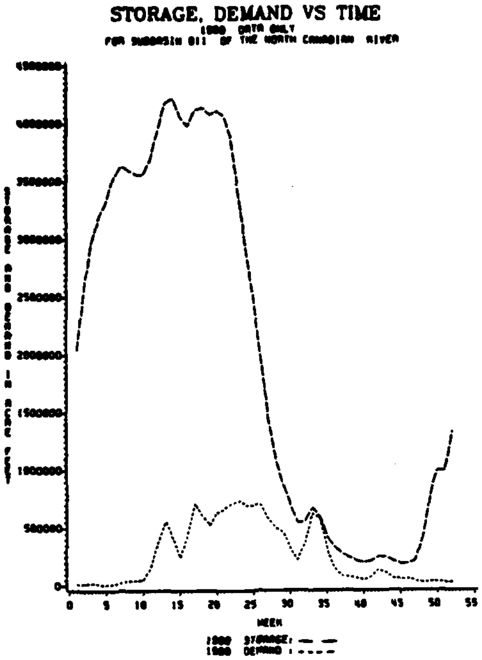
1950 DATA ONLY
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER

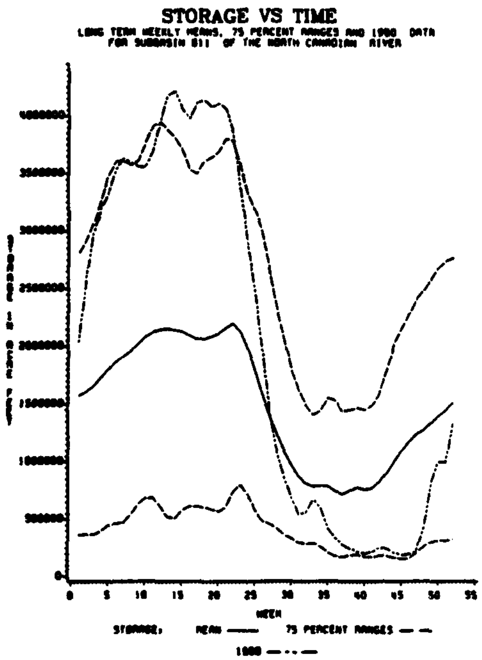


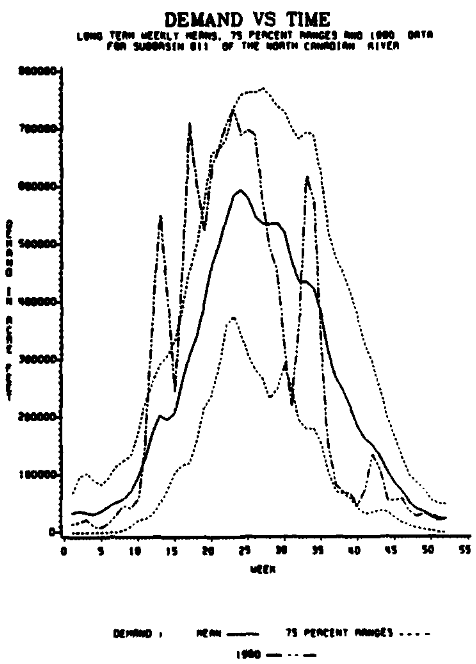
DEMAND VS TIME

LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1950 DATA
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER



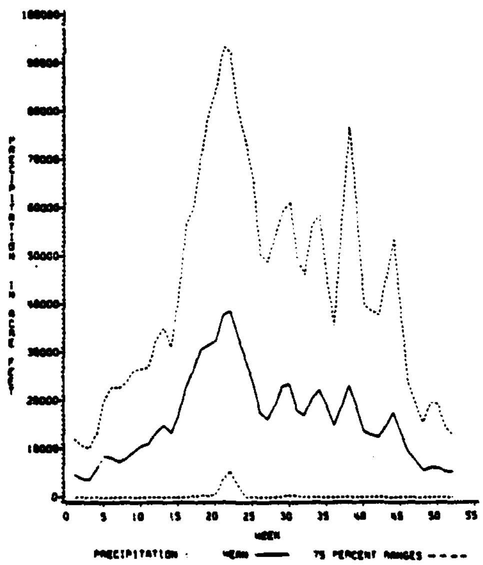

STORAGE, DEMAND VS TIME
1980 DATA ONLY
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
0 5 10 15 20 25 30 35 40 45 50 55
WEEK
1980 STORAGE
1980 DEMAND


STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE; MEAN 75 PERCENT RANGES
1980


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 811 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND ; MEAN 75 PERCENT RANGES
1980

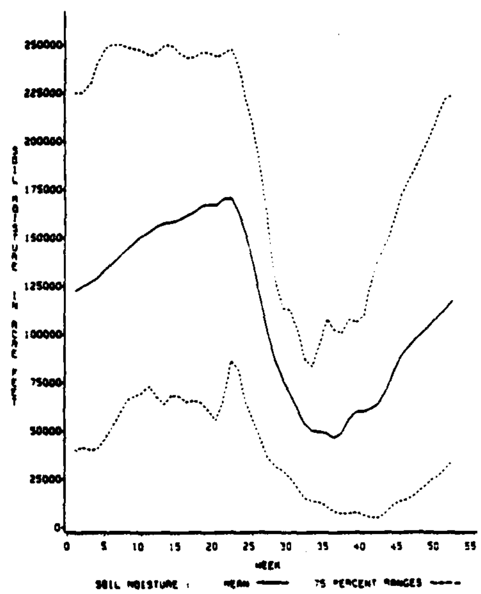
PRECIPITATION VS TIME

FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



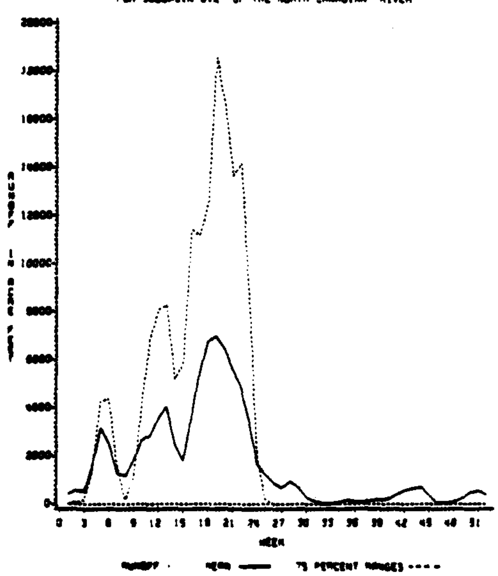
SOIL MOISTURE VS TIME

FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



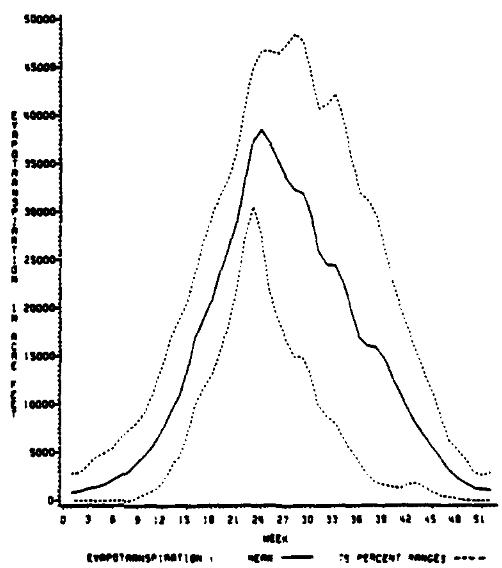
RUNOFF VS TIME

FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER

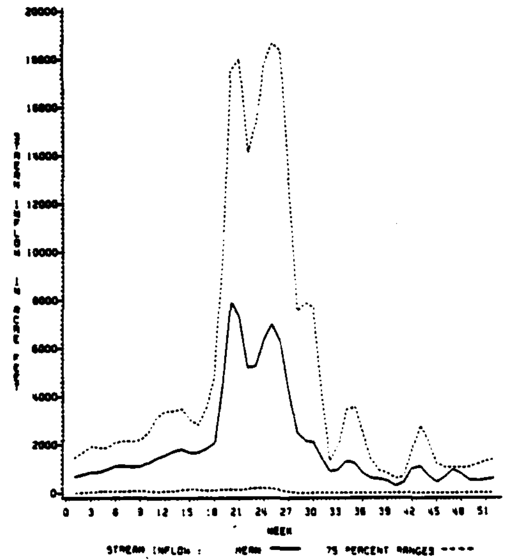


EVAPOTRANSPIRATION VS TIME

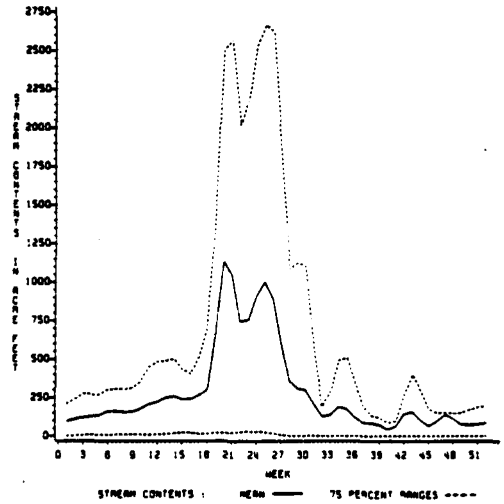
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



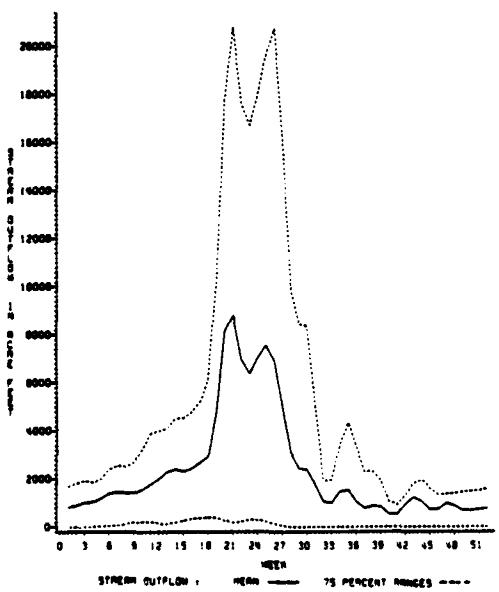
STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



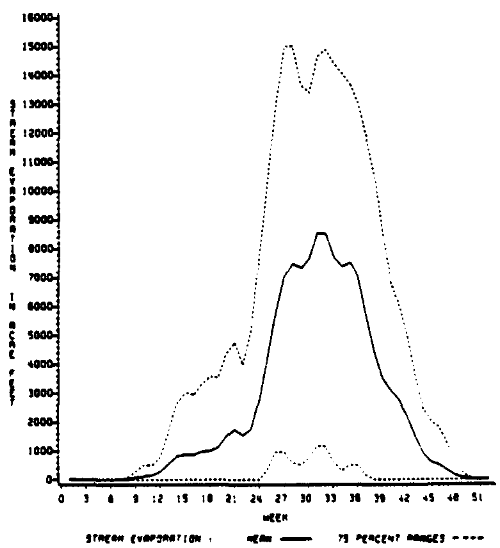
STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



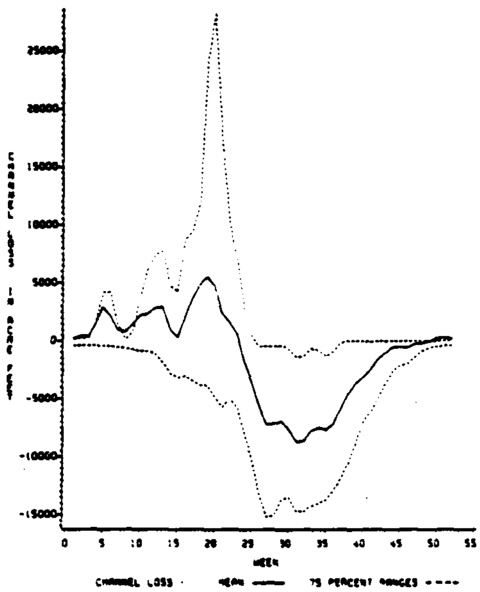
STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



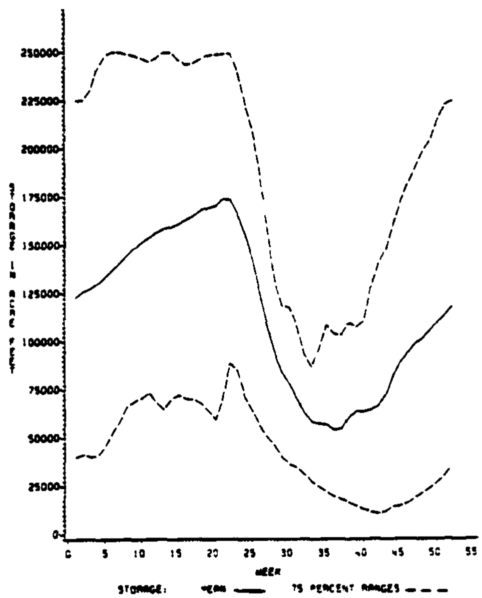
STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



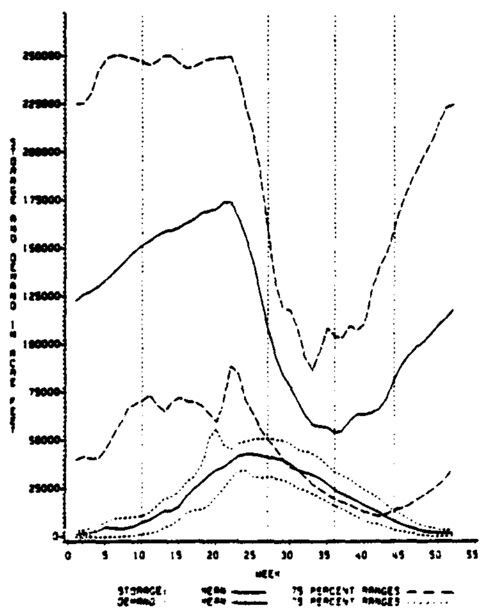
CHANNEL LOSS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



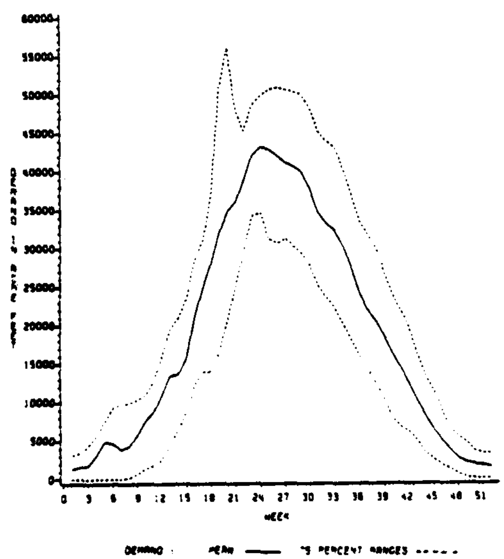
STORAGE VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



STORAGE, DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



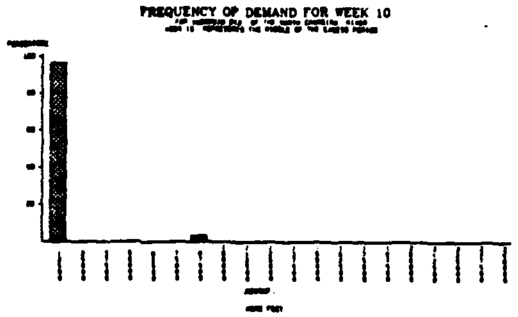
Joint frequency table for subbasin B12, week 10 (mid-excess period).

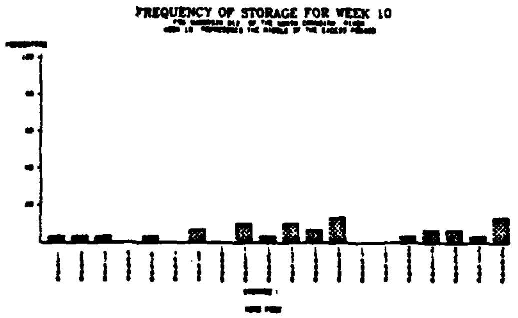
0	0	0	0	1	1	0
0	0	4	10	10	1	25
0	0	0	0	1	1	2
0	0	0	0	0	1	1
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	4	10	12	4	30

DEMAND: 1, 10, 70, 150, 245

STORAGE: 1, 10, 70, 150, 245

Storage and demand in thousands of acre feet.





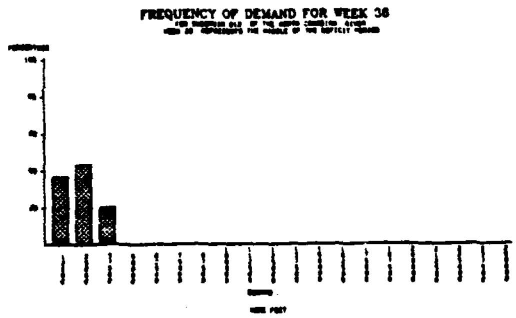
Joint frequency table for subbasin B12, week 36 (mid-deficit period).

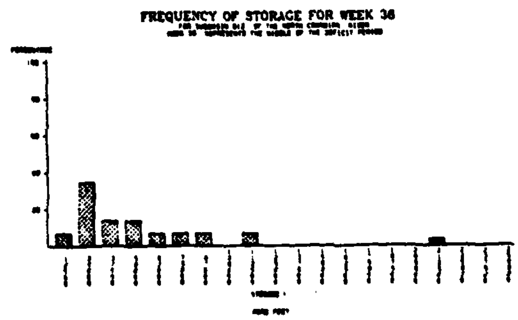
0	0	3	0	0	0	3
0	0	3	1	0	0	4
0	1	8	6	4	3	22
0	0	0	0	1	0	1
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	1	14	7	5	3	30

DEMAND: 15, 17, 35, 60, 105

STORAGE: 15, 17, 35, 60, 105

Storage and demand in thousands of acre feet.

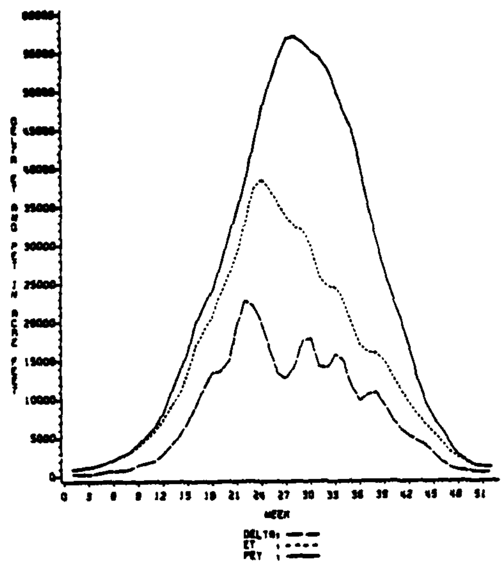




DELTA, ET AND PET VS TIME

LONG TERM WEEKLY MEANS

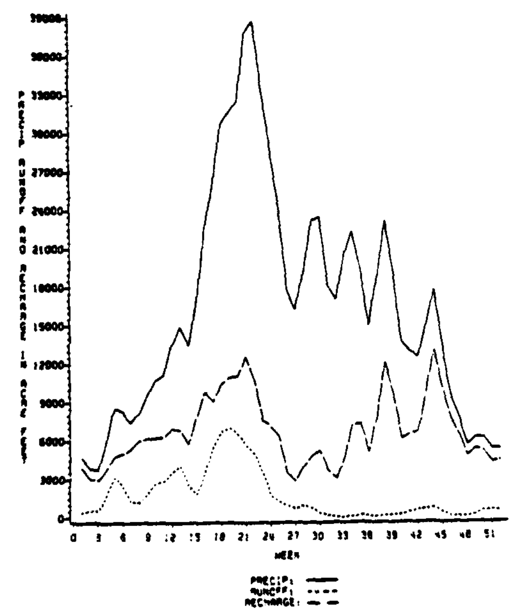
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER

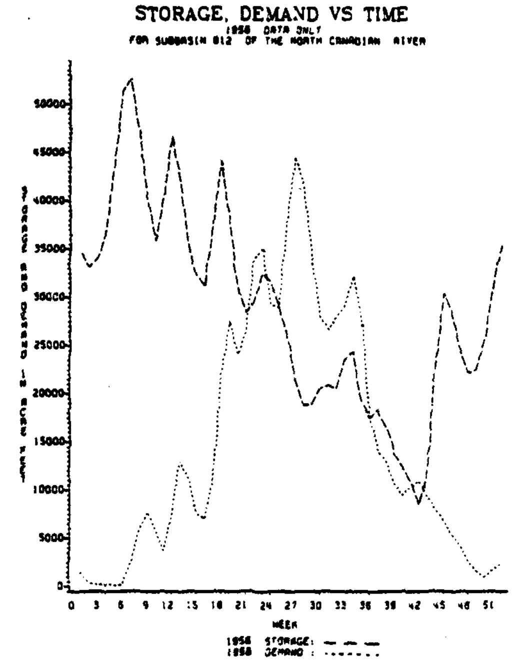


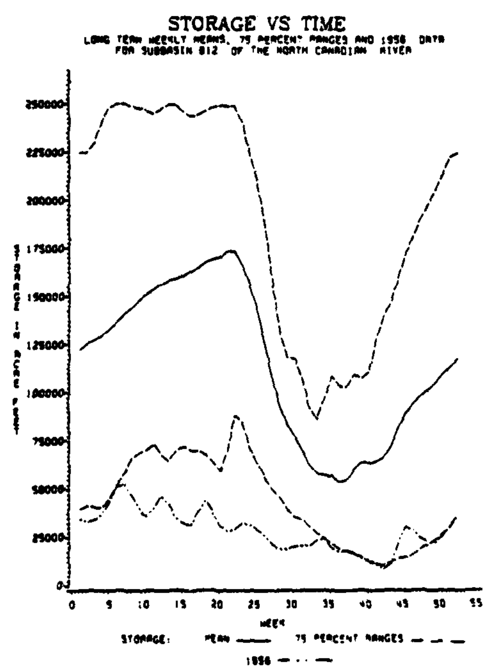
PRECIP, RUNOFF AND RECHARGE VS TIME

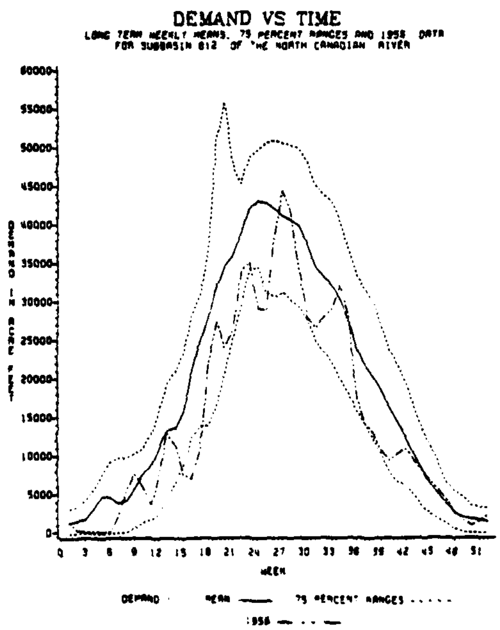
LONG TERM WEEKLY MEANS

FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



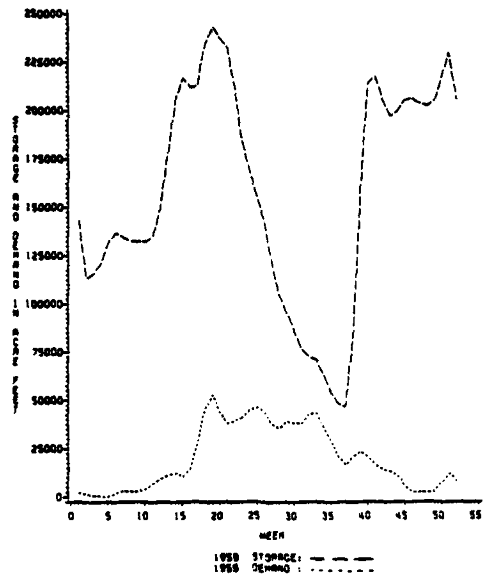

STORAGE, DEMAND VS TIME
1958 DATA ONLY
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER
WEEK
1958 STORAGE:
1958 DEMAND :


STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1958


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND MEAN 75 PERCENT RANGES
1958

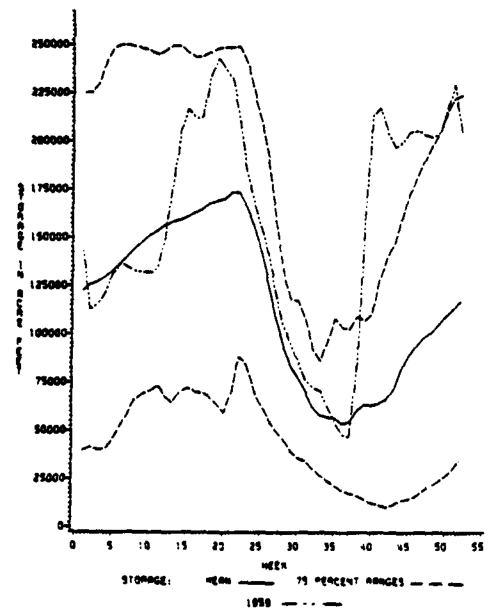
STORAGE, DEMAND VS TIME

1959 DATA ONLY
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER



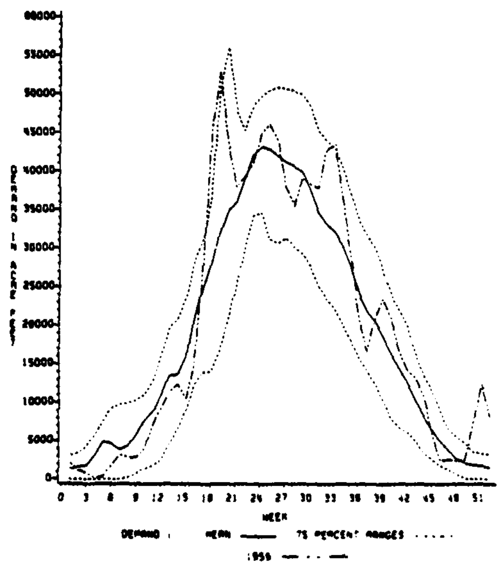
STORAGE VS TIME

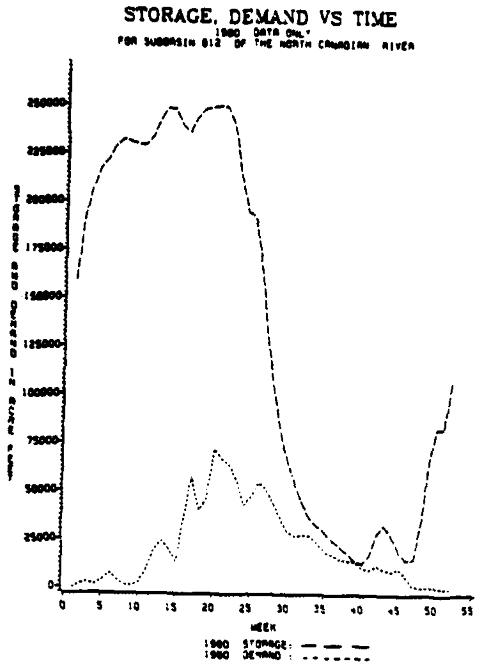
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1959 DATA
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER

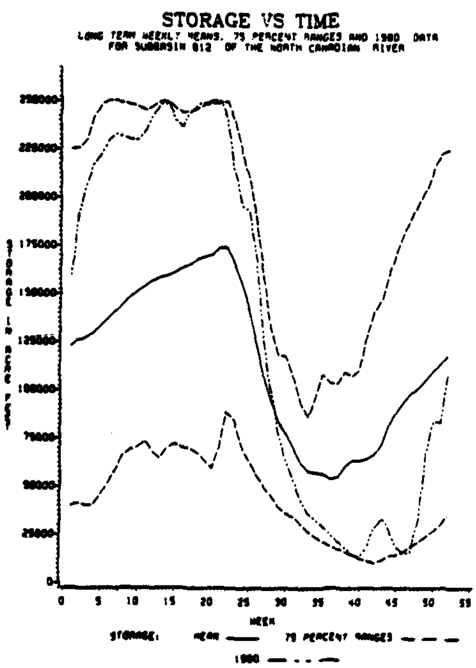


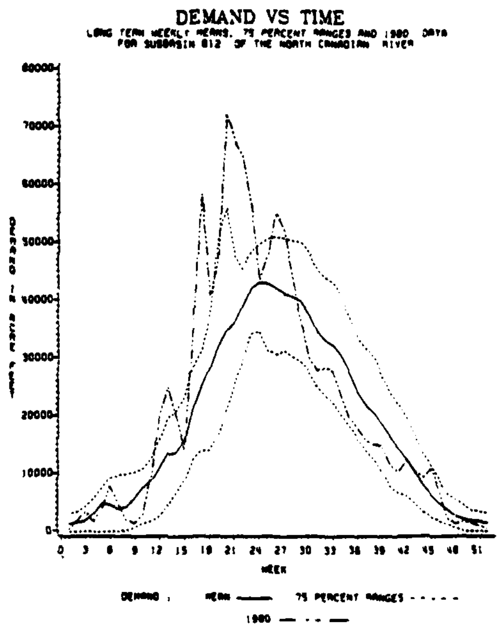
DEMAND VS TIME

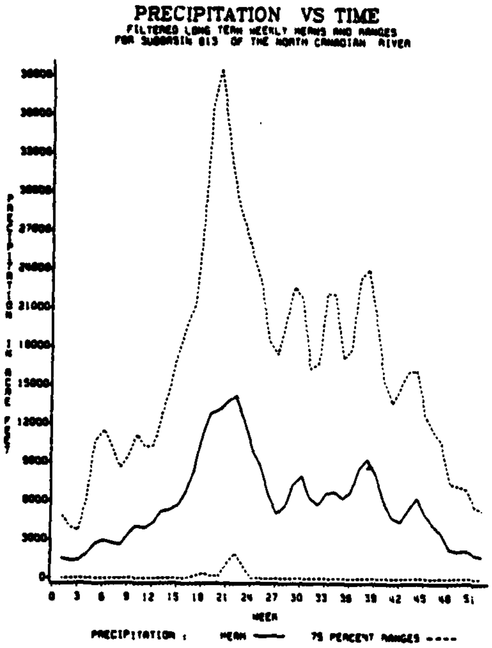
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1959 DATA
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER

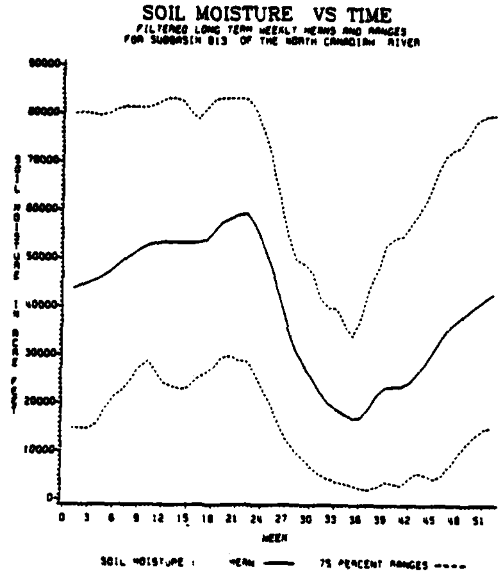


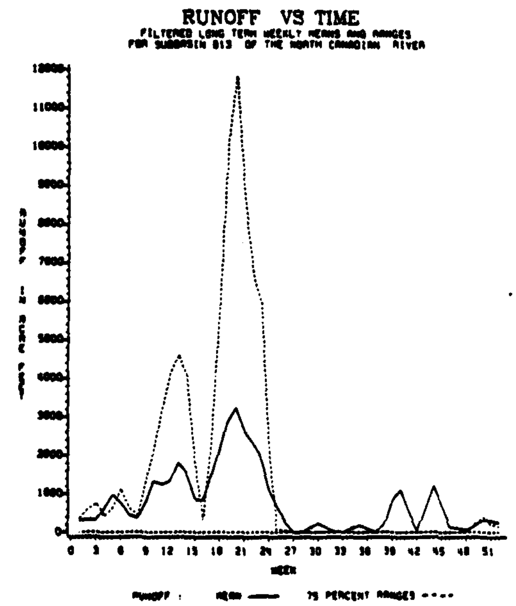

STORAGE, DEMAND VS TIME
1980 DATA ONLY
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER
250000
225000
200000
175000
150000
125000
100000
75000
50000
25000
0
0 5 10 15 20 25 30 35 40 45 50 55
WEEK
1980 STORAGE:
1980 DEMAND :

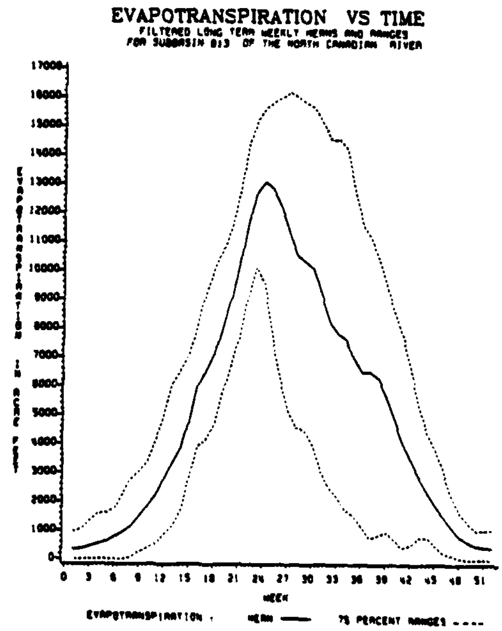

STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER
250000
225000
200000
175000
150000
125000
100000
75000
50000
25000
0
0 5 10 15 20 25 30 35 40 45 50 55
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1980

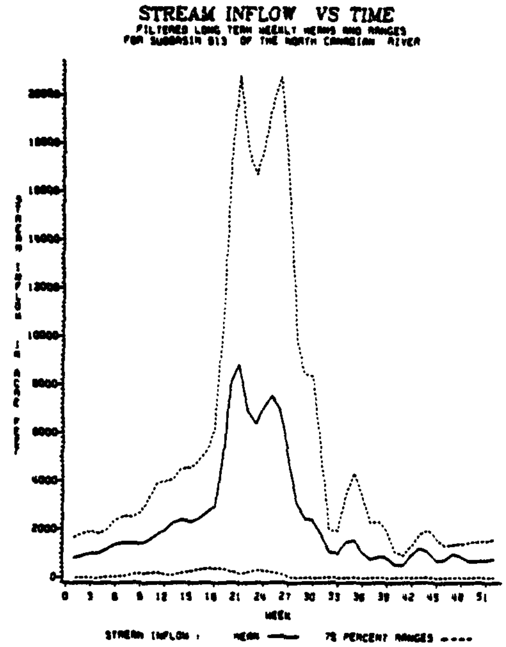

DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 812 OF THE NORTH CANADIAN RIVER
80000
70000
60000
50000
40000
30000
20000
10000
0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1980

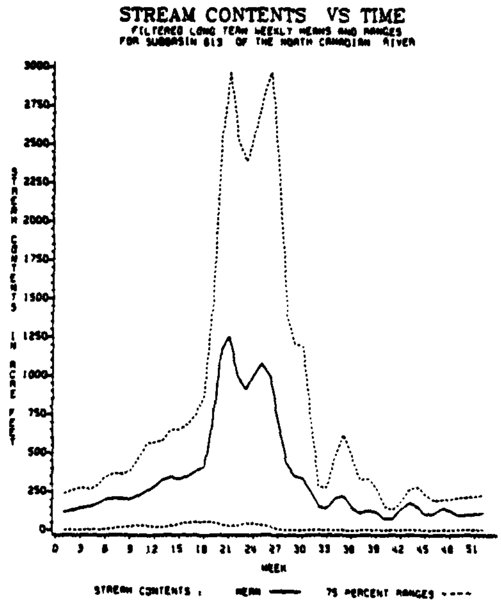

PRECIPITATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
PRECIPITATION : MEAN —— 75 PERCENT RANGES ----

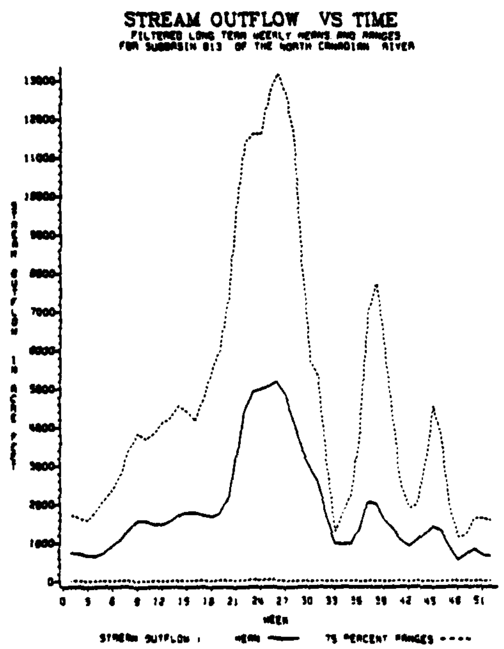

SOIL MOISTURE VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
SOIL MOISTURE : MEAN —— 75 PERCENT RANGES ----

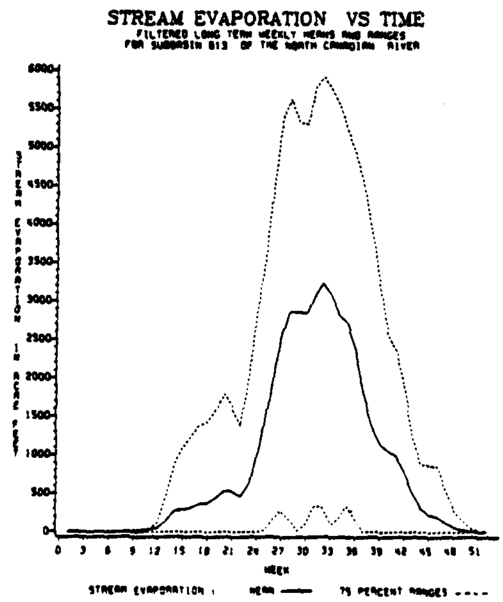

RUNOFF VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
RUNOFF : MEAN —— 75 PERCENT RANGES ----


EVAPOTRANSPIRATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
EVAPOTRANSPIRATION : MEAN —— 75 PERCENT RANGES ----


STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
STREAM INFLOW : MEAN 75 PERCENT RANGES

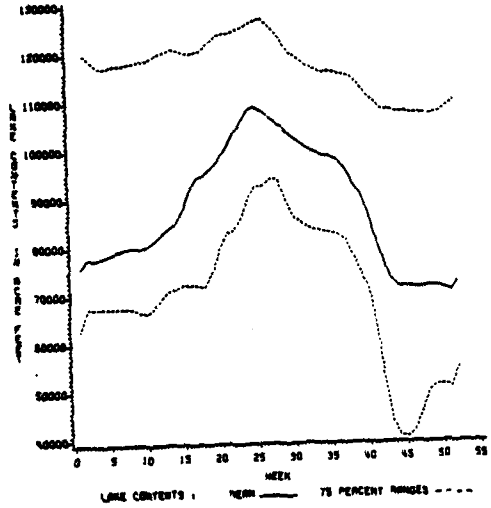

STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
STREAM CONTENTS IN ACRE FEET
WEEK
STREAM CONTENTS : MEAN 75 PERCENT RANGES


STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
STREAM OUTFLOW : MEAN 75 PERCENT RANGES


STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
STREAM EVAPORATION IN ACRE FEET
WEEK
STREAM EVAPORATION : MEAN 75 PERCENT RANGES

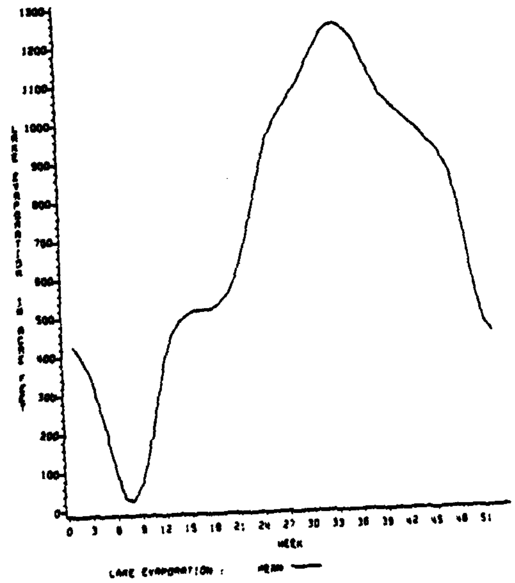
LAKE CONTENTS VS TIME

FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER



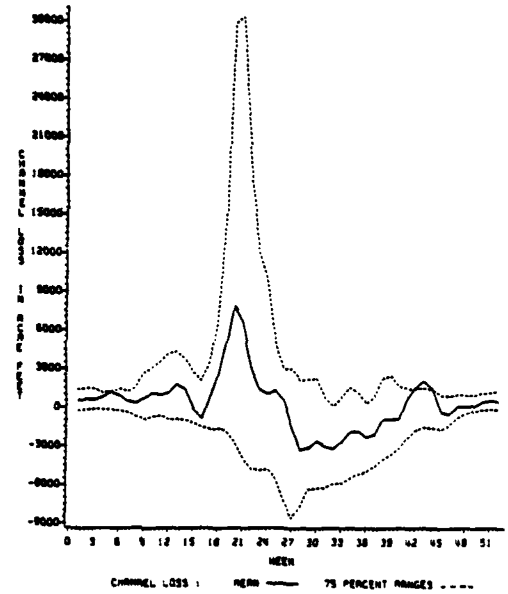
LAKE EVAPORATION VS TIME

FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER



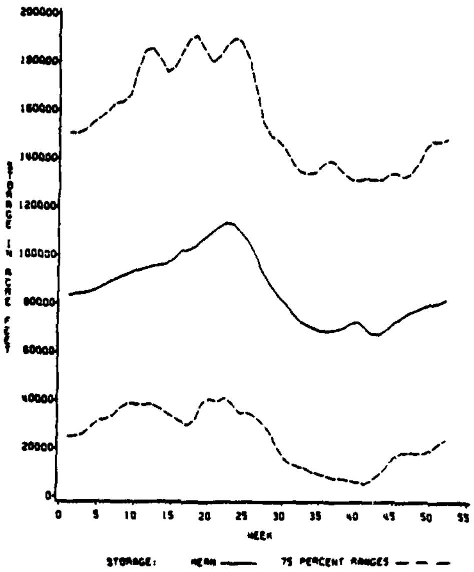
CHANNEL LOSS VS TIME

FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER



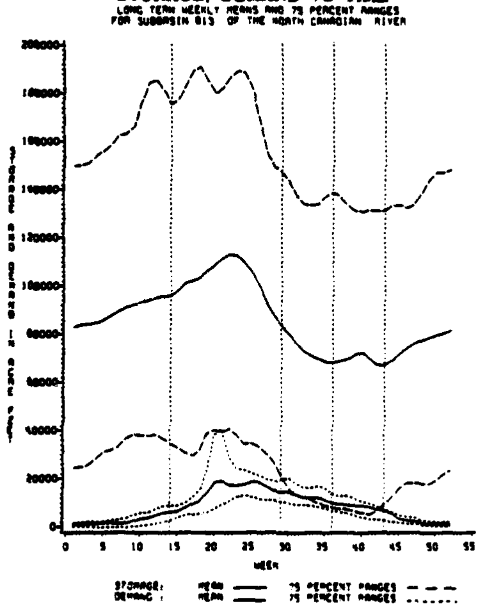
STORAGE VS TIME

LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER



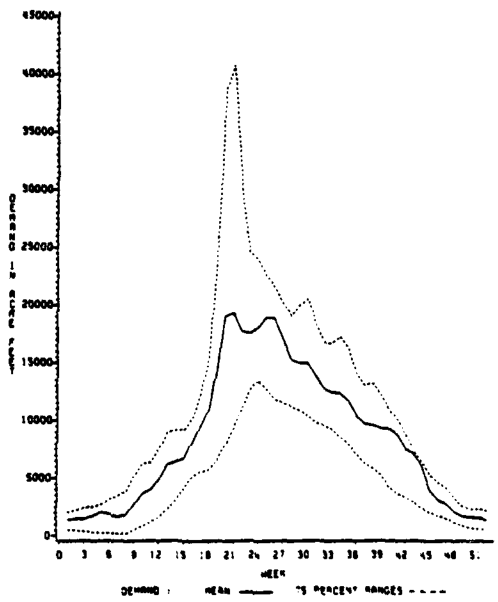
STORAGE, DEMAND VS TIME

LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER



DEMAND VS TIME

LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER

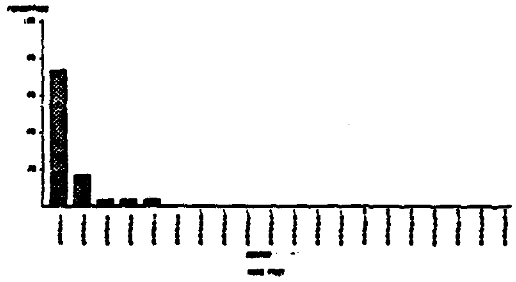


Joint frequency table for subbasin 813, week 14 (mid-surplus period).

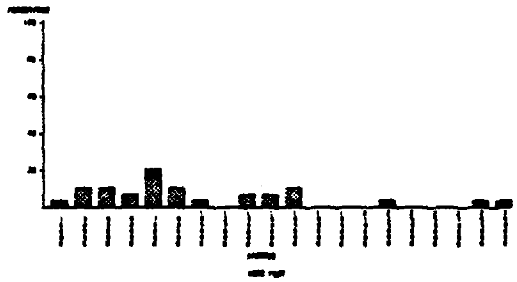
							DEMAND
0	0	1	2	2	7	12	4
0	0	3	8	1	3	15	8
0	0	0	2	0	1	3	36
0	0	0	0	0	0	0	96
0	0	0	0	0	0	0	176
0	0	0	0	0	0	0	
0	0	4	12	3	11	30	
STORAGE: 4	8	36	96	176			

Storage and demand in thousands of acre feet.

FREQUENCY OF DEMAND FOR WEEK 14



FREQUENCY OF STORAGE FOR WEEK 14

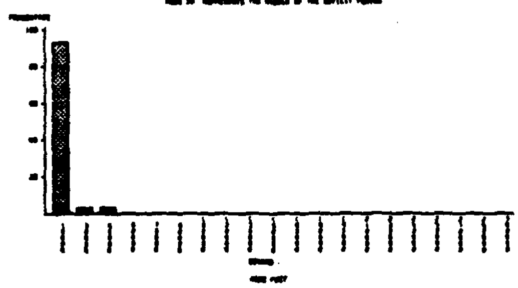


Joint frequency table for subbasin 813, week 36 (mid-deficit period).

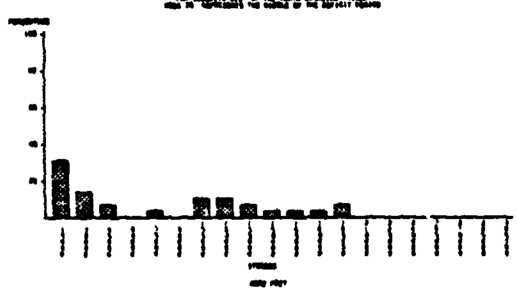
							DEMAND
3	0	0	0	0	0	3	8
0	0	0	0	0	0	0	9
0	0	3	7	6	3	19	46
0	0	0	3	4	1	8	68
0	0	0	0	0	0	0	138
0	0	0	0	0	0	0	
3	0	3	10	10	4	30	
STORAGE: 8	9	14	68	138			

Storage and demand in thousands of acre feet.

FREQUENCY OF DEMAND FOR WEEK 36

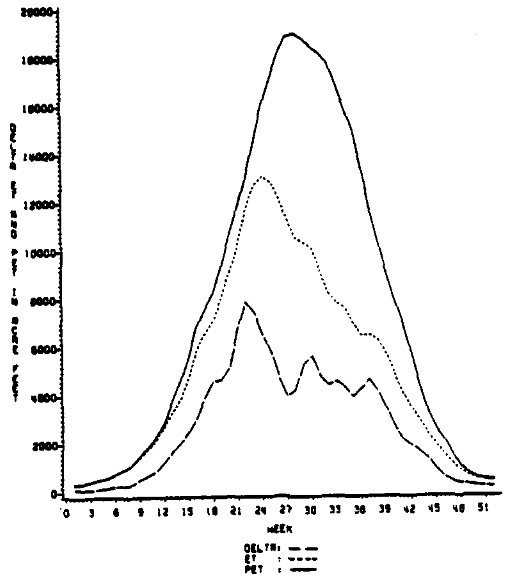


FREQUENCY OF STORAGE FOR WEEK 36



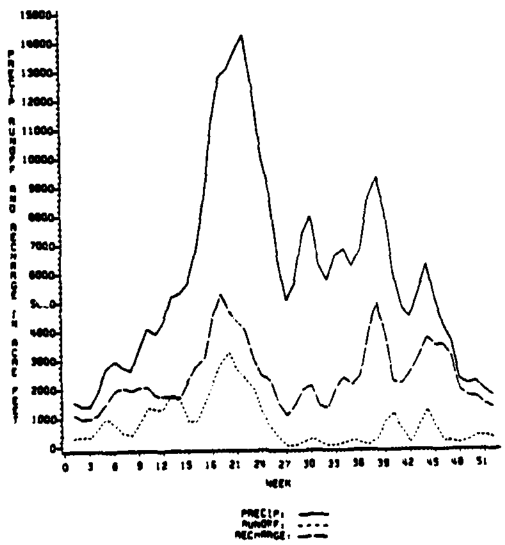
DELTA, ET AND PET VS TIME

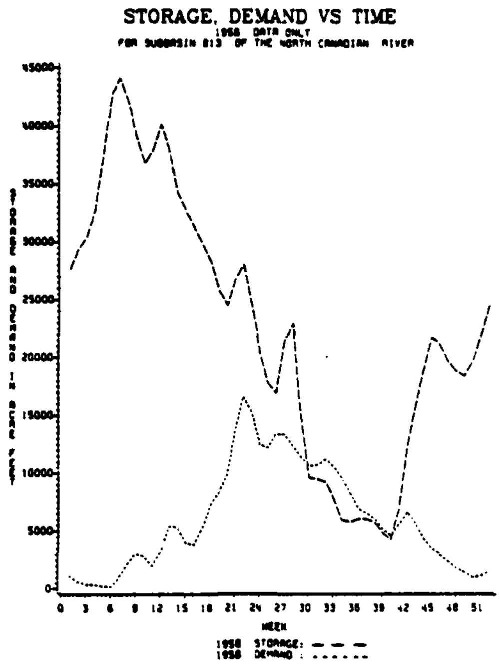
LONG TERM WEEKLY MEANS
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER

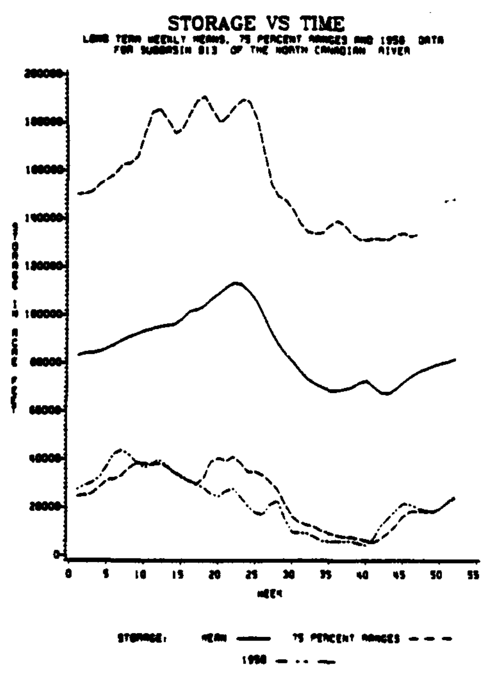


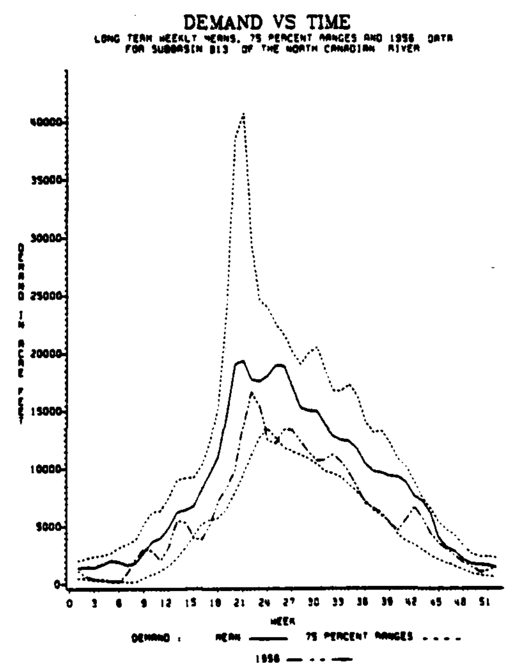
PRECIP, RUNOFF AND RECHARGE VS TIME

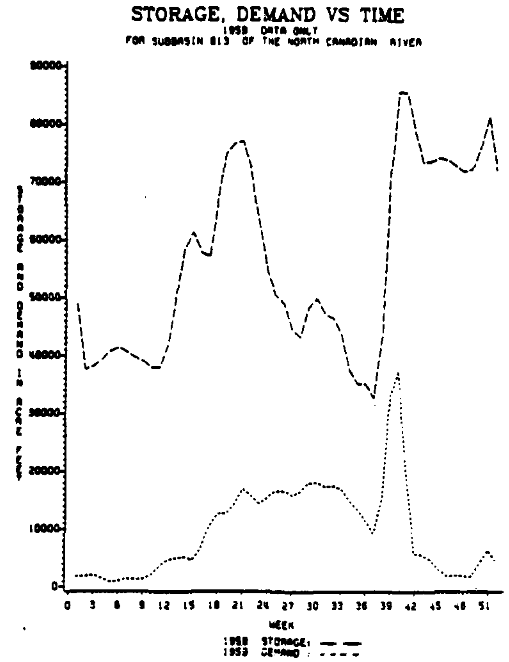
LONG TERM WEEKLY MEANS
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER

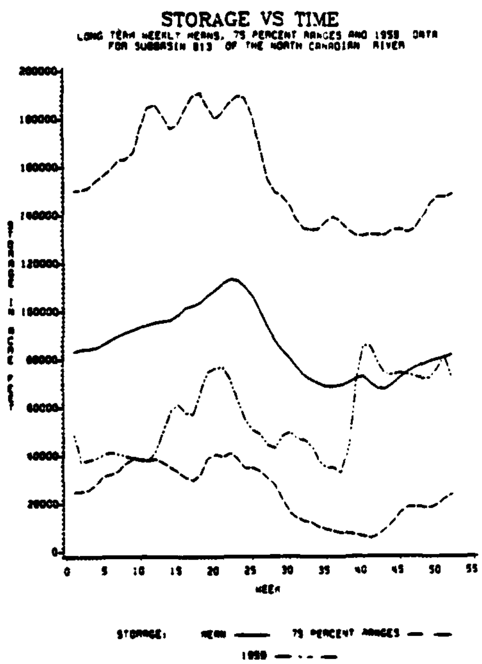


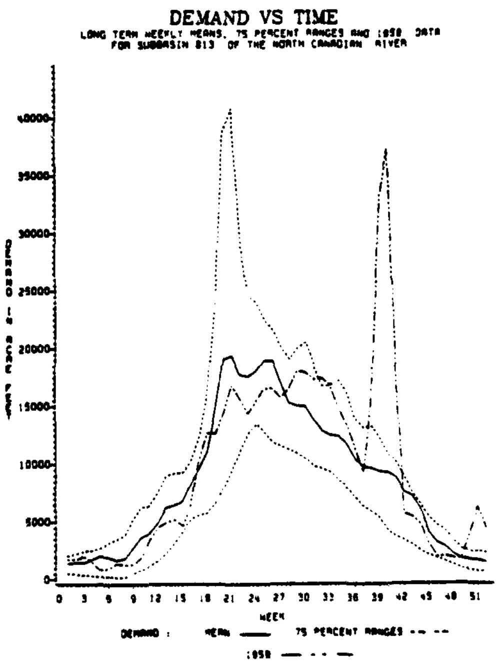

STORAGE, DEMAND VS TIME
1958 DATA ONLY
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51
WEEK
1958 STORAGE:
1958 DEMAND :


STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
0 5 10 15 20 25 30 35 40 45 50 55
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1958


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
40000
35000
30000
25000
20000
15000
10000
5000
0
0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1958


STORAGE, DEMAND VS TIME
1958 DATA ONLY
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
1958 STORAGE:
1959 DEMAND :


STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1958


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1958

AD-A119 723 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 8/8
THE IMPACT OF CLIMATOLOGICAL VARIABILITY ON SURFACE WATER SUPPL--ETC(U)
1982 C C OLSEN.
UNCLASSIFIED AFIT/CI/NR/82-51T NL

3 of 3

END
DATE
FILMED
11-82
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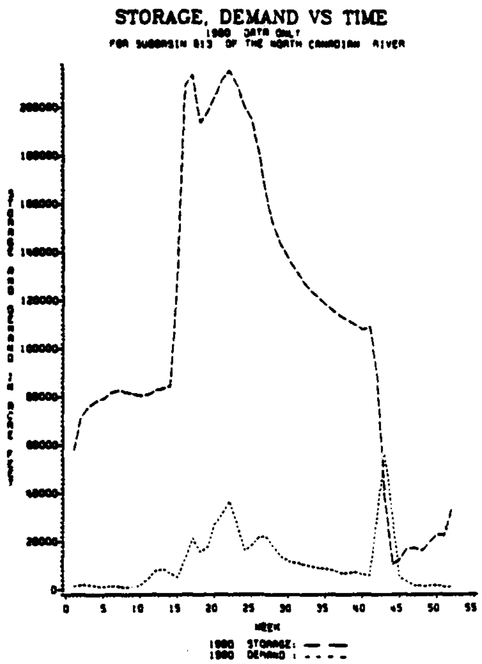
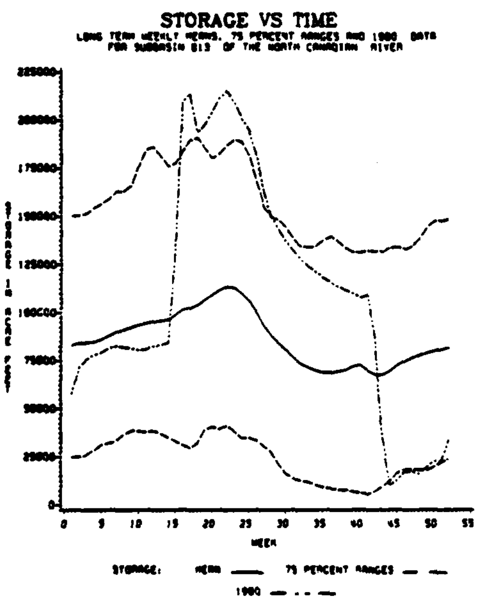
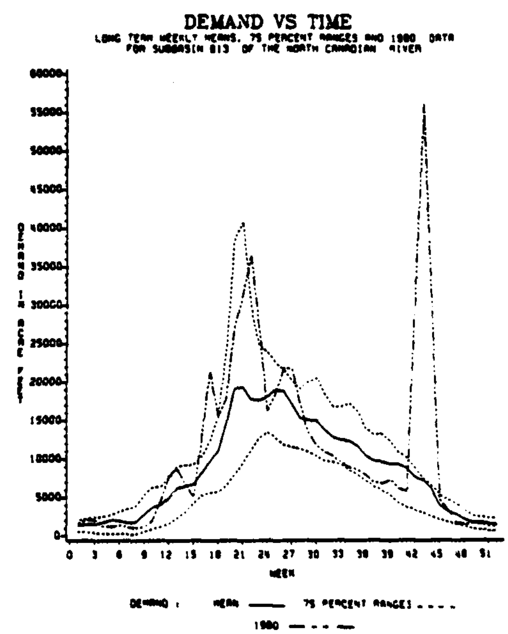
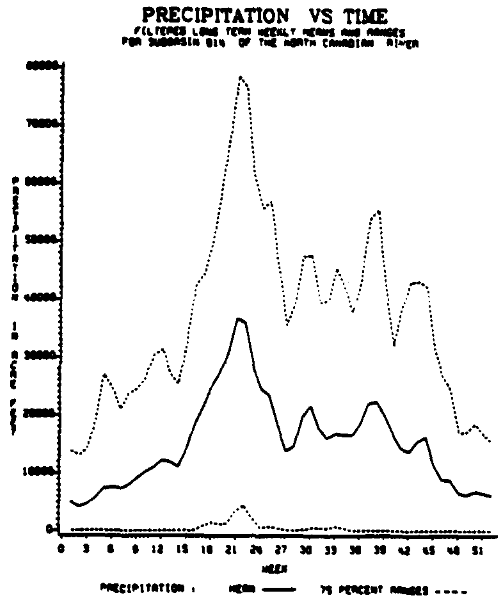
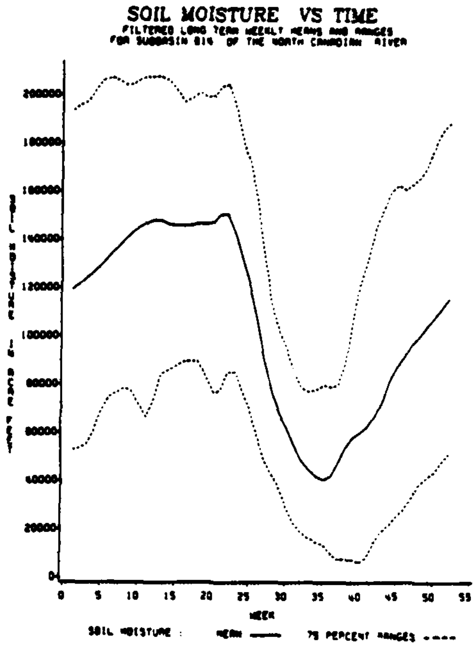
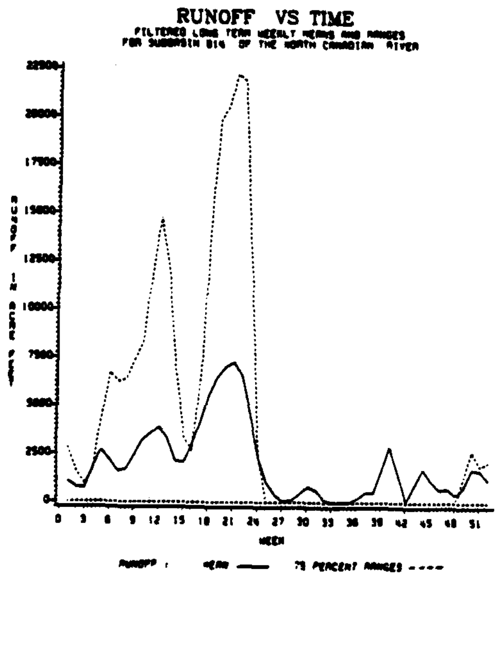

STORAGE, DEMAND VS TIME
1980 DATA ONLY
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
1980 STORAGE:
1980 DEMAND :

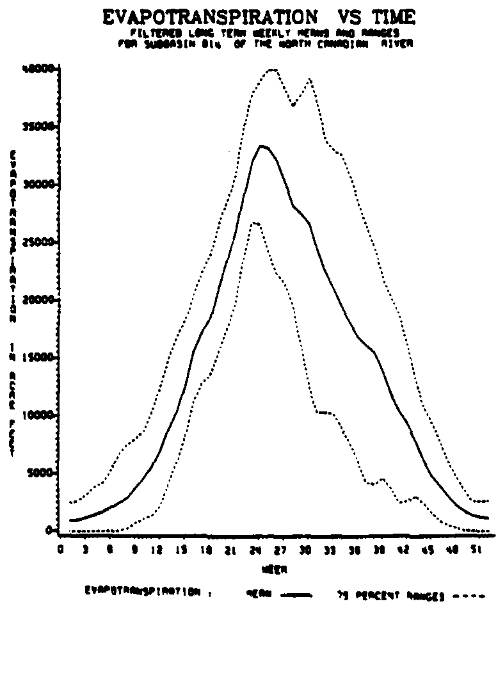

STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1980

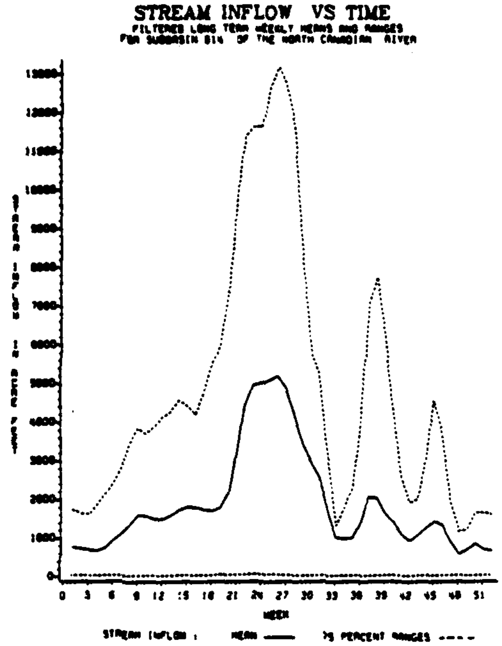

DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 813 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1980

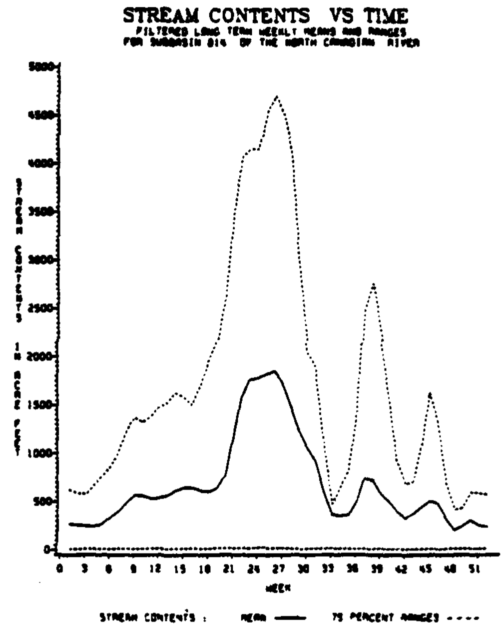

PRECIPITATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
PRECIPITATION : MEAN —— 75 PERCENT RANGES ----

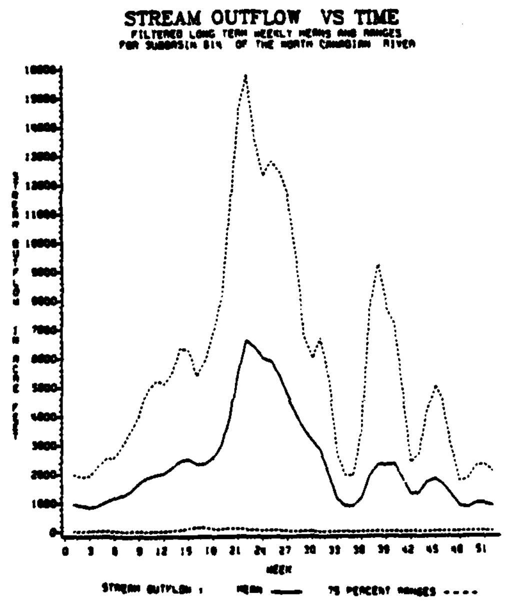

SOIL MOISTURE VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
SOIL MOISTURE : MEAN —— 75 PERCENT RANGES ----

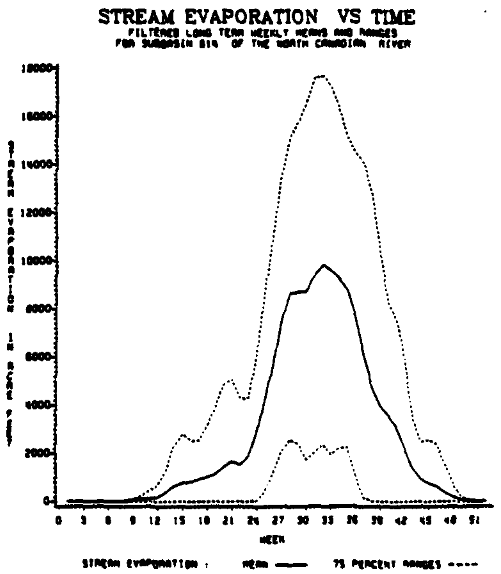

RUNOFF VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
RUNOFF : MEAN —— 75 PERCENT RANGES ----

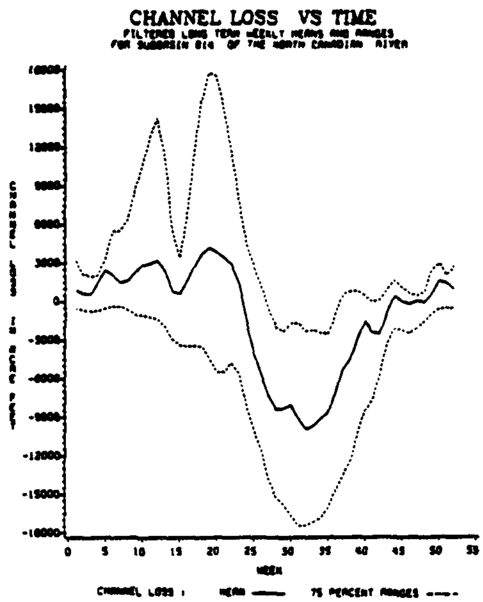

EVAPOTRANSPIRATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
EVAPOTRANSPIRATION : MEAN —— 75 PERCENT RANGES ----

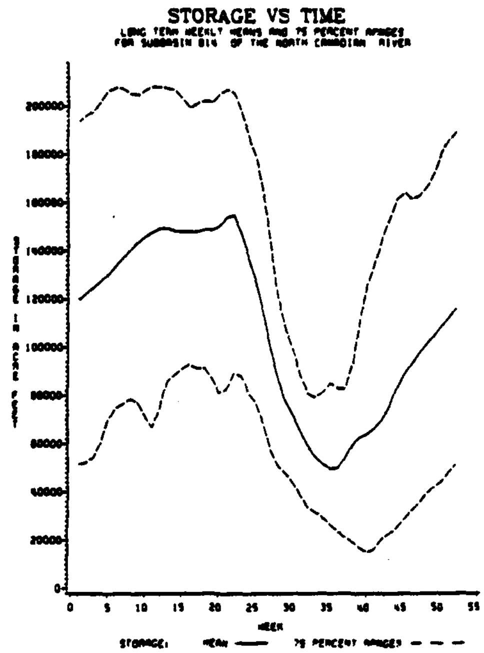

STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
STREAM INFLOW : MEAN —— 75 PERCENT RANGES ----

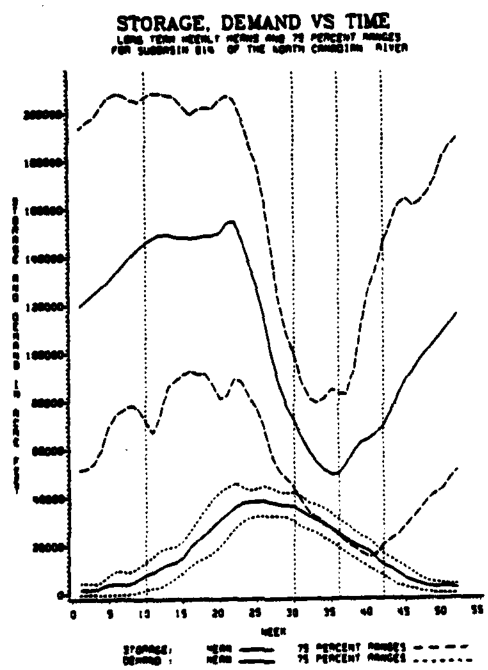

STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
STREAM CONTENTS : MEAN —— 75 PERCENT RANGES ----

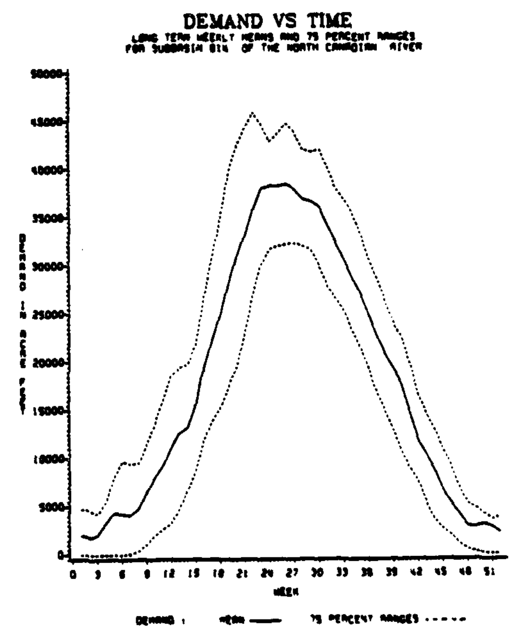

STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
STREAM OUTFLOW : MEAN —— 75 PERCENT RANGES ----

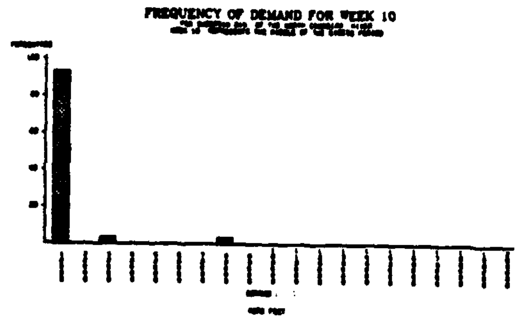

STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
WEEK
STREAM EVAPORATION : MEAN —— 75 PERCENT RANGES ----


CHANNEL LOSS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 814 OF THE NORTH CANADIAN RIVER
WEEK
CHANNEL LOSS : MEAN 75 PERCENT RANGES


STORAGE VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 814 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES


STORAGE, DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 814 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
DEMAND : MEAN 75 PERCENT RANGES


DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 814 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND : MEAN 75 PERCENT RANGES



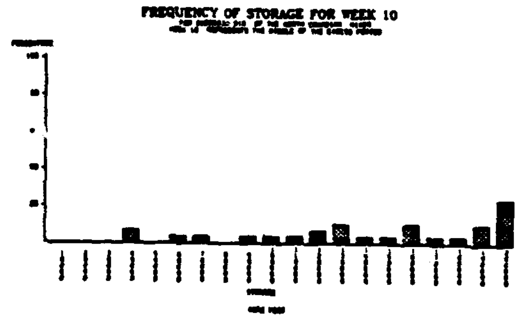
Joint frequency table for subbasin 814, week 10 (mid-surplus period).

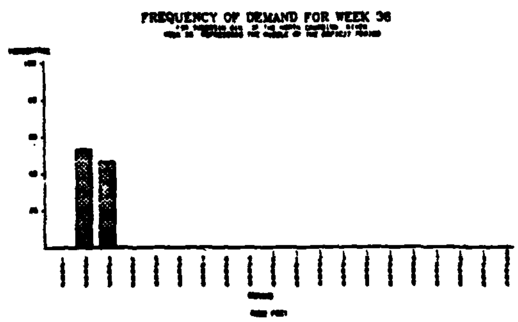
0	0	0	0	1	1	2	2
0	0	3	10	10	2	25	14
0	0	0	0	2	0	2	70
0	0	0	0	0	1	1	146
0	0	0	0	0	0	0	296
0	0	0	0	0	0	0	
0	0	3	10	13	4	30	
2	14	70	146	296			

DEMAND

STORAGE

Storage and demand in thousands of acre feet.





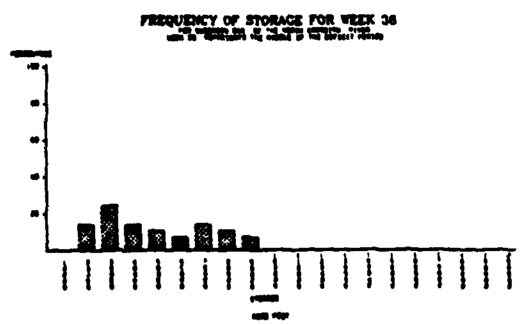
Joint frequency table for subbasin 814, week 36 (mid-deficit period).

0	1	1	1	0	1	4	20
1	1	2	3	4	0	11	24
0	1	2	3	6	2	14	32
0	0	0	1	0	0	1	56
0	0	0	0	0	0	0	84
0	0	0	0	0	0	0	
1	3	5	8	10	3	30	
20	24	32	50	84			

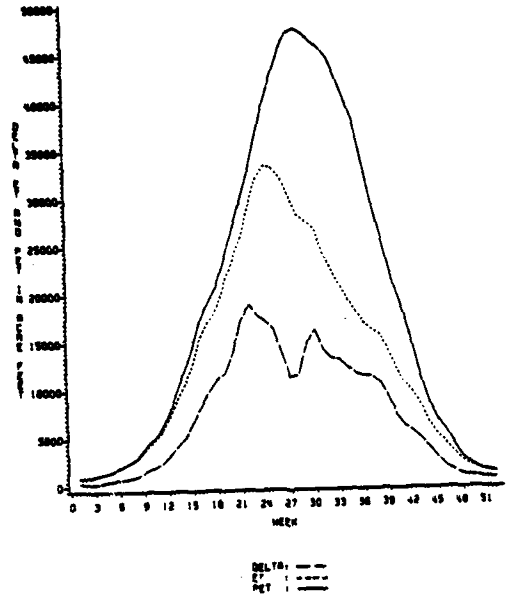
DEMAND

STORAGE

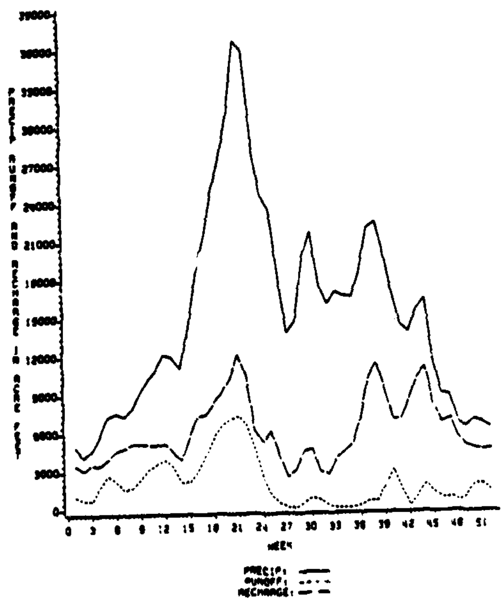
Storage and demand in thousands of acre feet.

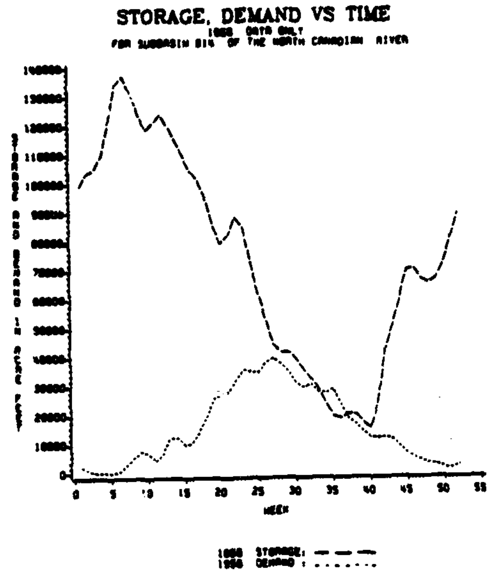


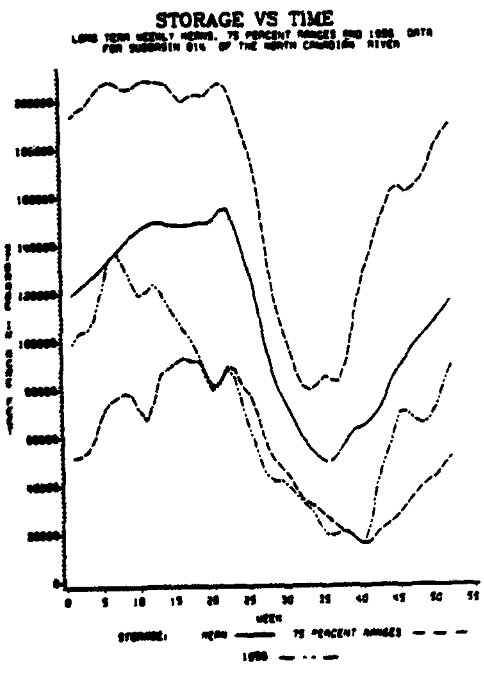
DELTA, ET AND PET VS TIME
LONG TERM WEEKLY MEANS
FOR SUBBASIN 814 OF THE NORTH CANADIAN RIVER

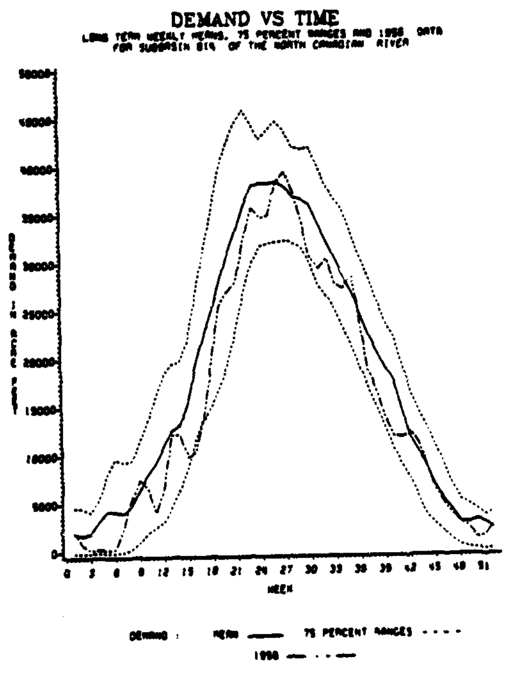


PRECIP, RUNOFF AND RECHARGE VS TIME
LONG TERM WEEKLY MEANS
FOR SUBBASIN 814 OF THE NORTH CANADIAN RIVER



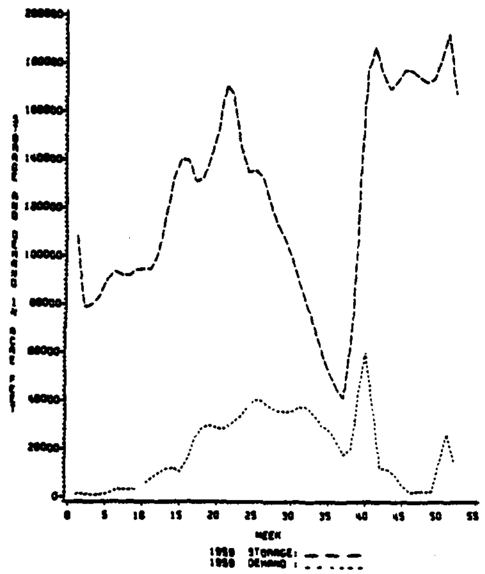

STORAGE, DEMAND VS TIME


STORAGE VS TIME


DEMAND VS TIME

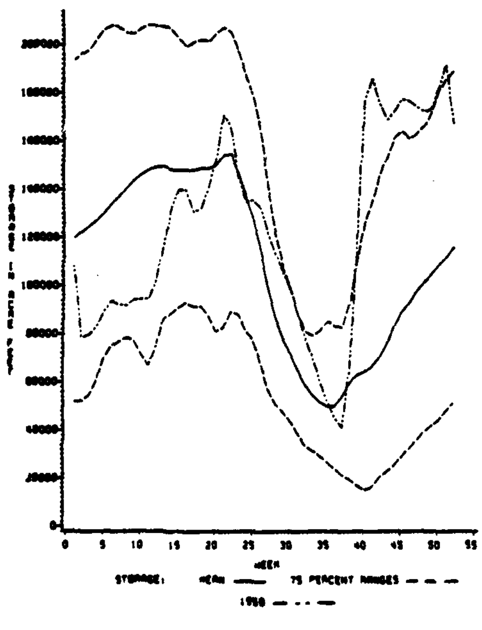
STORAGE, DEMAND VS TIME

1958 DATA ONLY
FOR SUBBASIN 81% OF THE NORTH CANADIAN RIVER



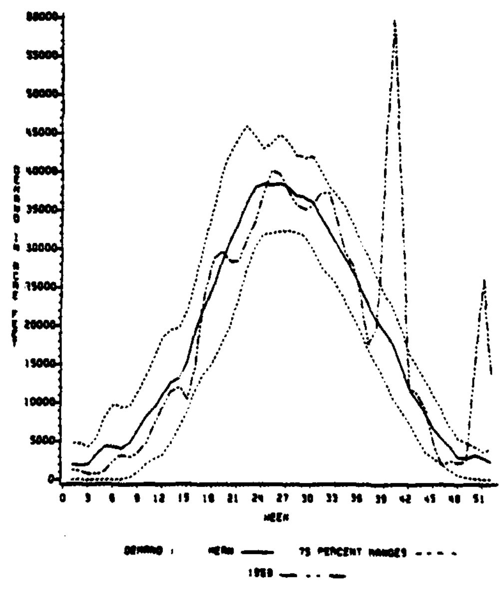
STORAGE VS TIME

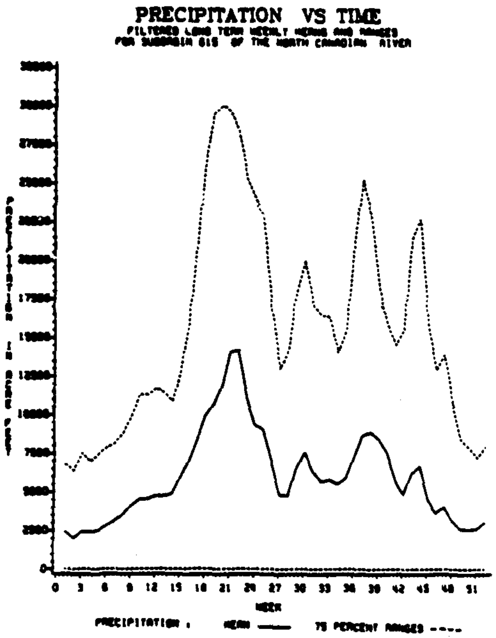
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 81% OF THE NORTH CANADIAN RIVER

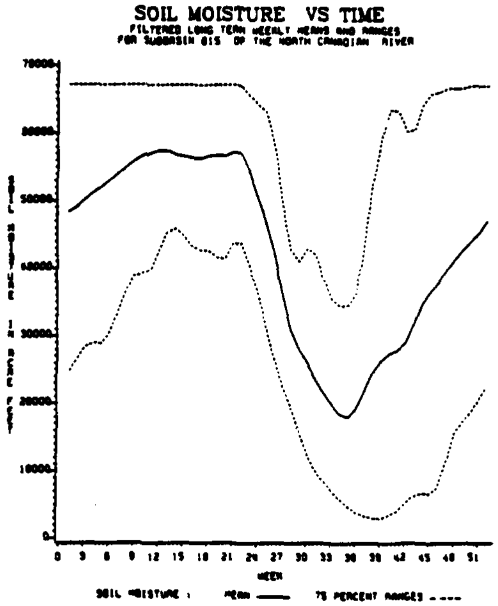


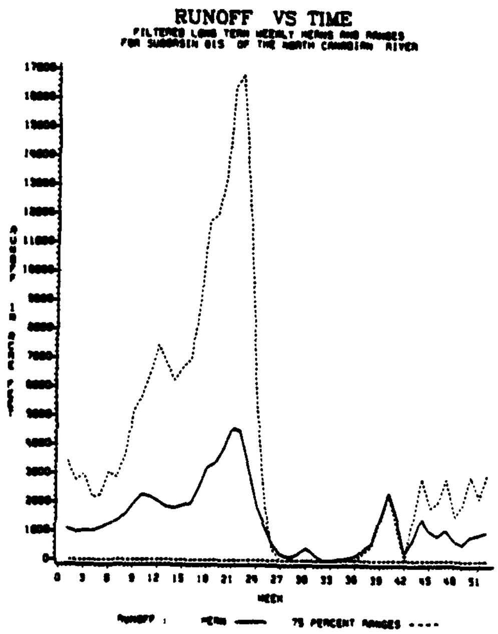
DEMAND VS TIME

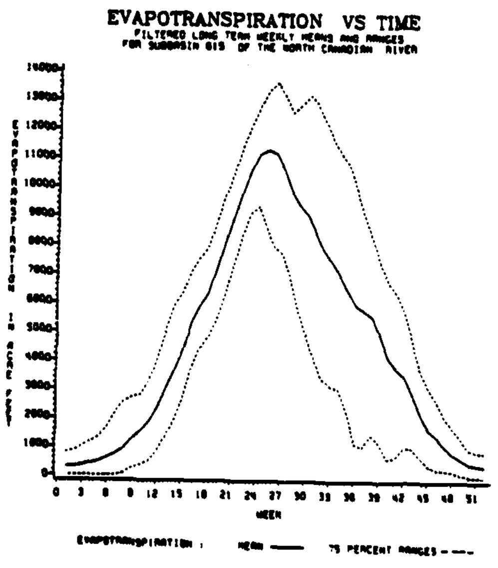
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1958 DATA
FOR SUBBASIN 81% OF THE NORTH CANADIAN RIVER

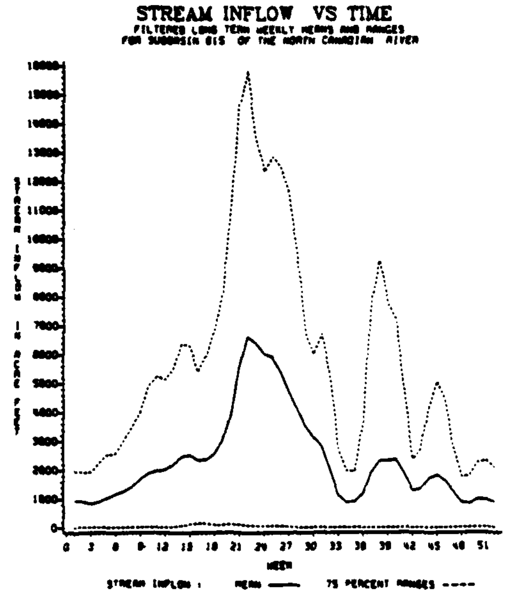


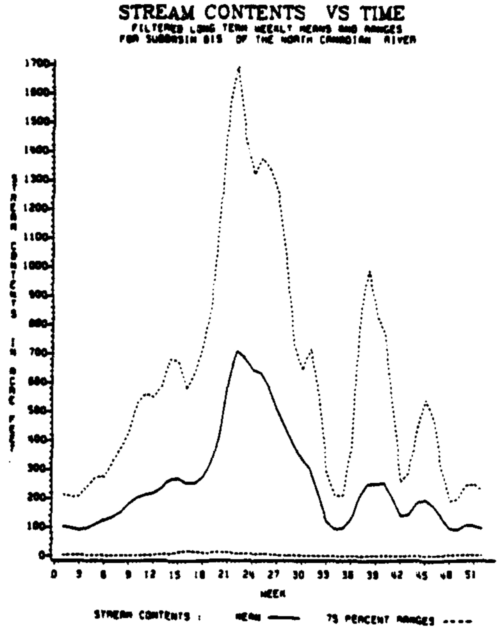

PRECIPITATION VS TIME
WEEK

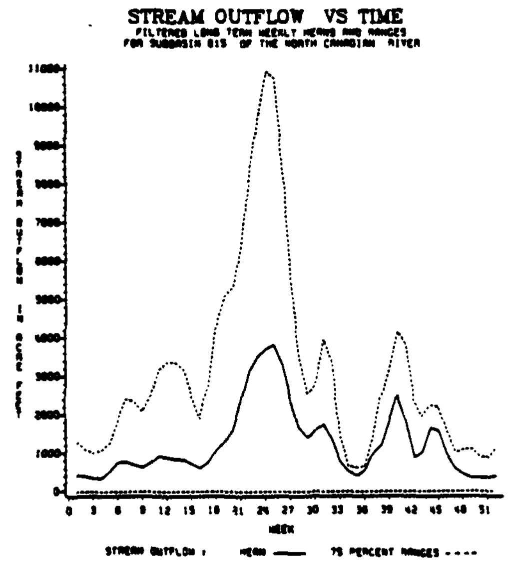

SOIL MOISTURE VS TIME
WEEK

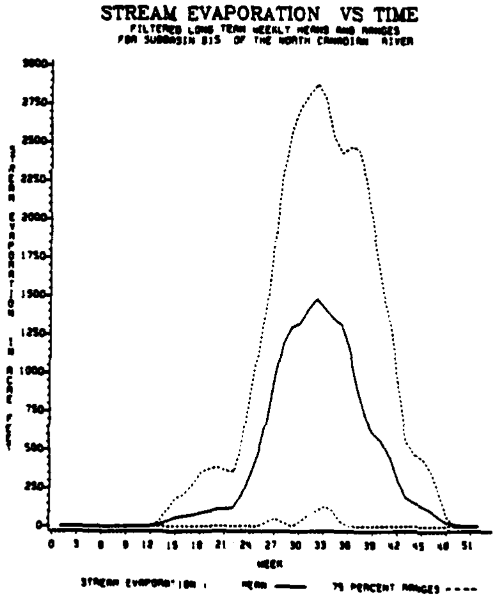

RUNOFF VS TIME
WEEK

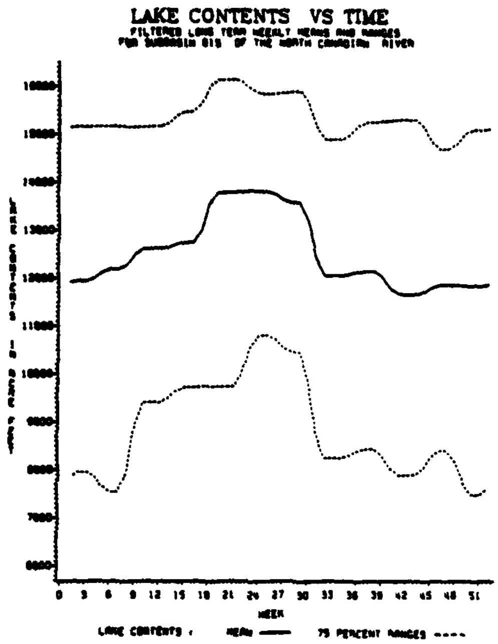

EVAPOTRANSPIRATION VS TIME
WEEK

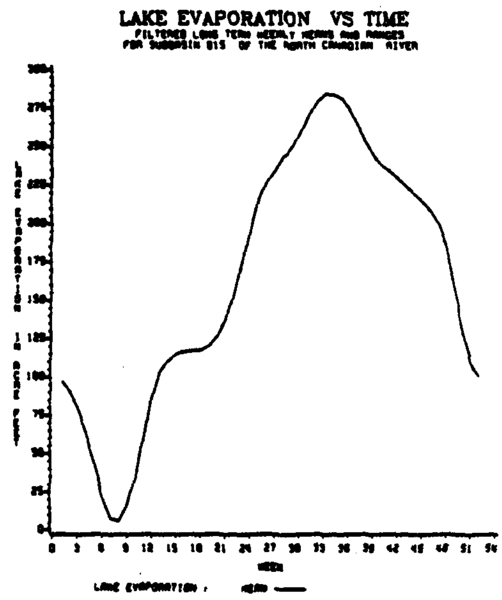

STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
WEEK
STREAM INFLOW : MEAN —— 75 PERCENT RANGES ----


STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
WEEK
STREAM CONTENTS : MEAN —— 75 PERCENT RANGES ----

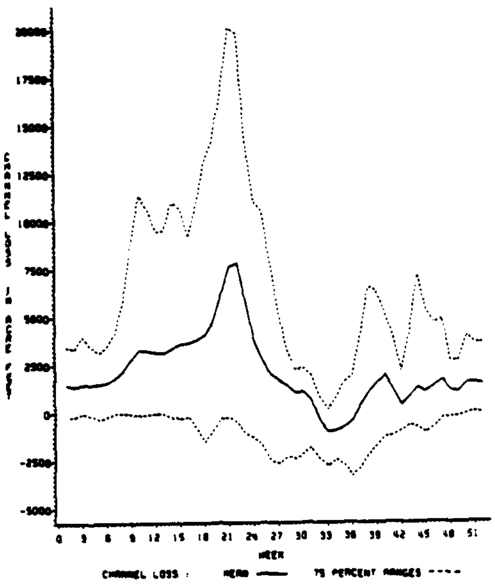

STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
WEEK
STREAM OUTFLOW : MEAN —— 75 PERCENT RANGES ----


STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
WEEK
STREAM EVAPORATION : MEAN —— 75 PERCENT RANGES ----


LAKE CONTENTS VS TIME

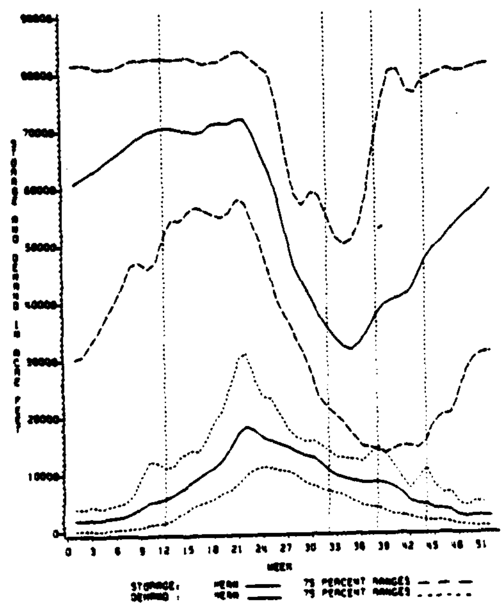

LAKE EVAPORATION VS TIME

CHANNEL LOSS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER

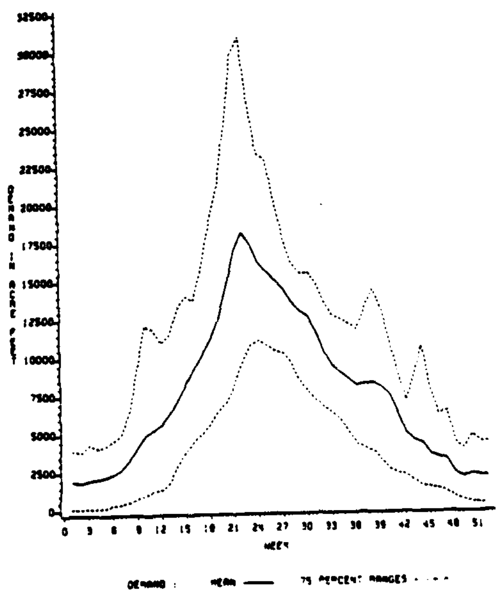


STORAGE VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER

STORAGE, DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER



DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER



FREQUENCY OF DEMAND FOR WEEK 12

Joint frequency table for subbasin 815, week 12 (mid-excess period).

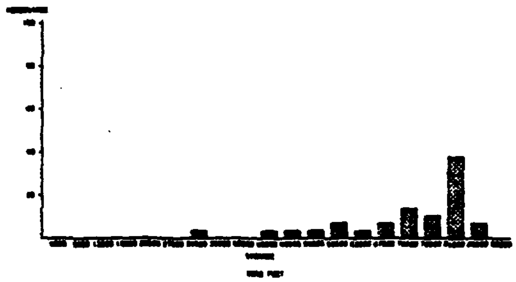
0	0	0	2	0	11	13	2
0	0	1	2	0	5	16	12
0	0	0	0	0	1	1	52
0	0	0	0	0	0	0	70
0	0	0	0	0	0	0	82
0	0	0	0	0	0	0	
0	0	1	4	0	17	36	
2	12	52	70	82			

DEMAND

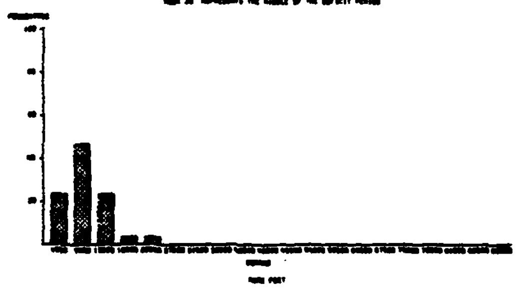
STORAGE

Storage and demand in thousands of acre feet.

FREQUENCY OF STORAGE FOR WEEK 12



FREQUENCY OF DEMAND FOR WEEK 38



Joint frequency table for subbasin 813, week 38 (mid-deficit period).

0	3	0	1	1	0	5	5
0	2	0	10	6	2	20	14
0	0	0	1	0	1	2	15
0	0	0	1	1	1	3	37
0	0	0	0	0	0	0	68
0	0	0	0	0	0	0	
0	5	0	13	0	4	30	
5	14	15	37	68			

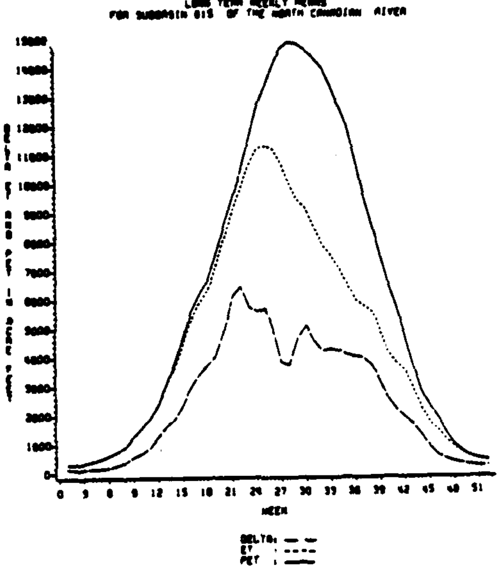
DEMAND

STORAGE

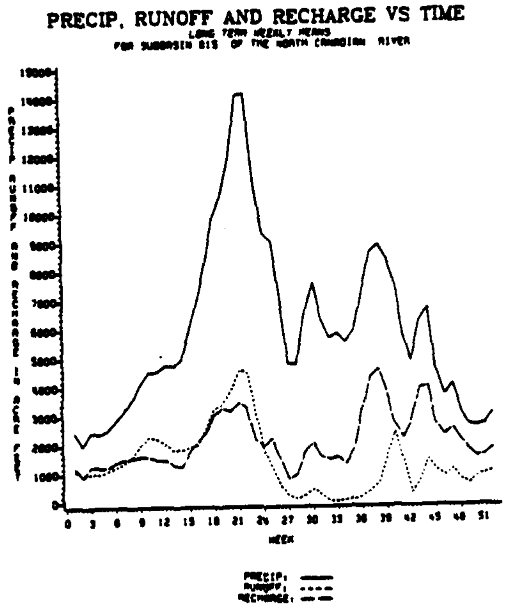
Storage and demand in thousands of acre feet.

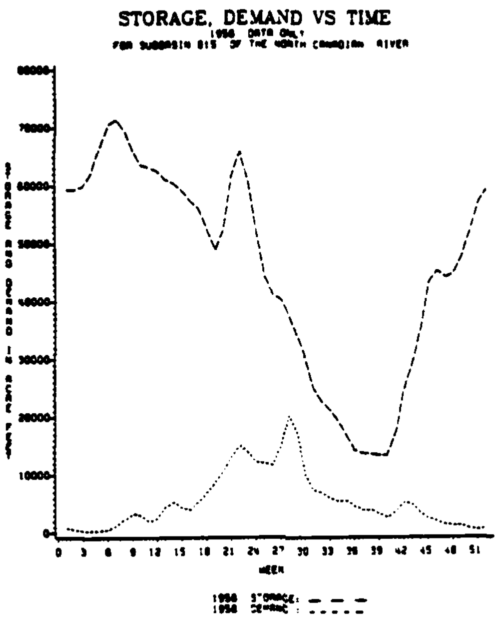
FREQUENCY OF STORAGE FOR WEEK 38

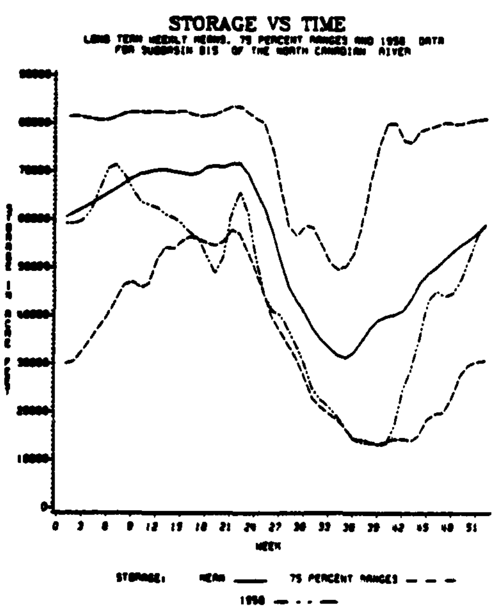
DELTA, ET AND PET VS TIME

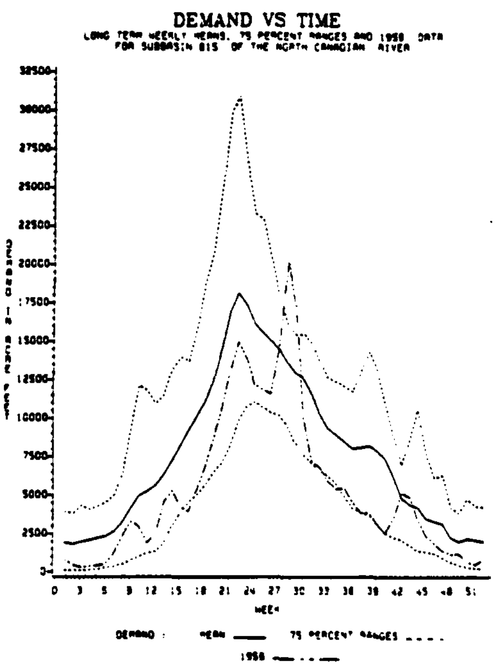


PRECIP, RUNOFF AND RECHARGE VS TIME

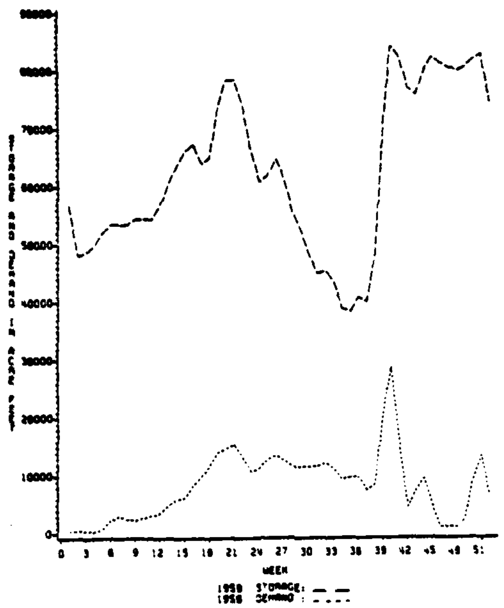



STORAGE, DEMAND VS TIME
WEEK

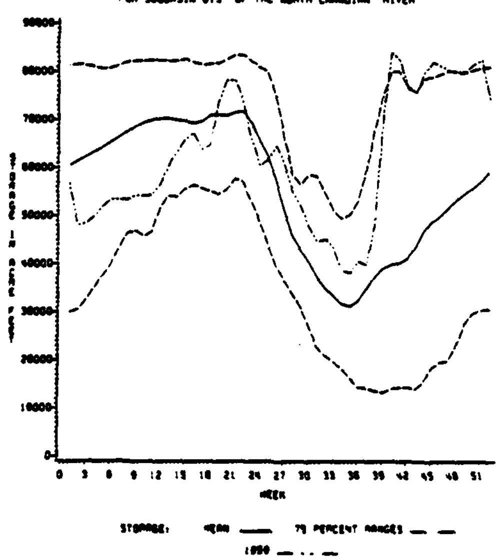

STORAGE VS TIME
WEEK


DEMAND VS TIME
WEEK

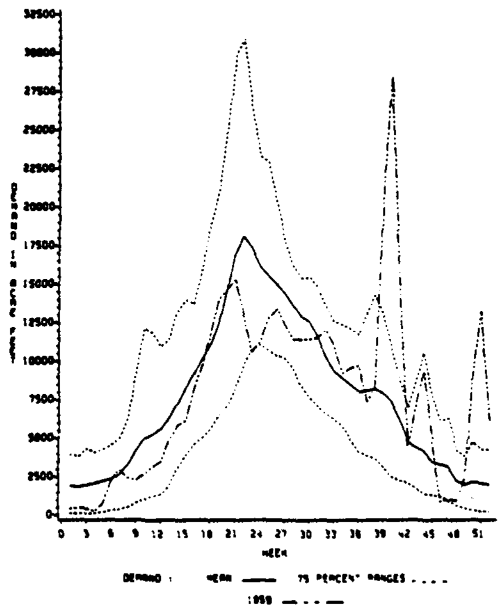
STORAGE, DEMAND VS TIME

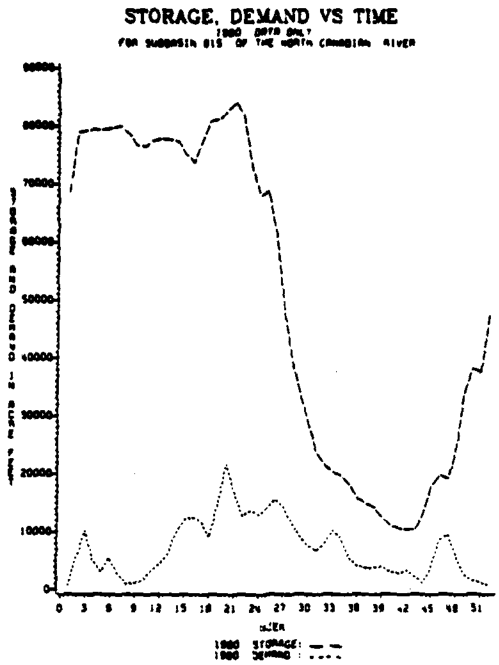


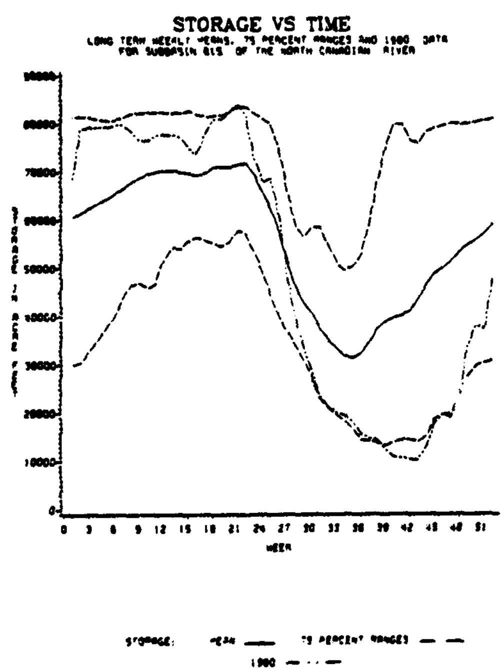
STORAGE VS TIME

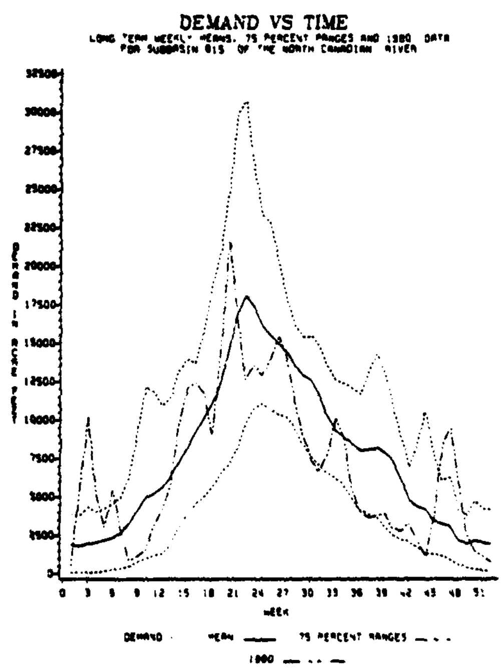


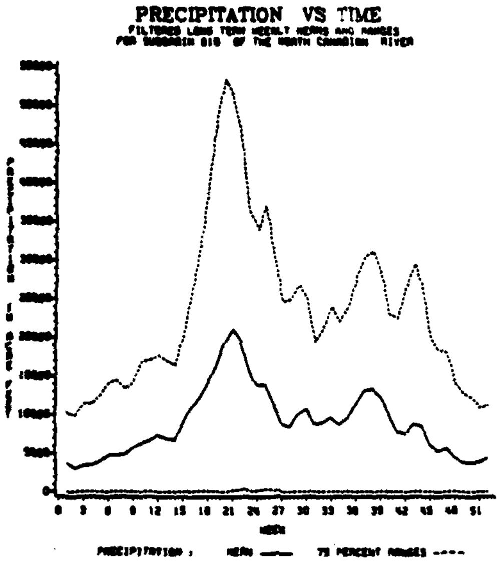
DEMAND VS TIME

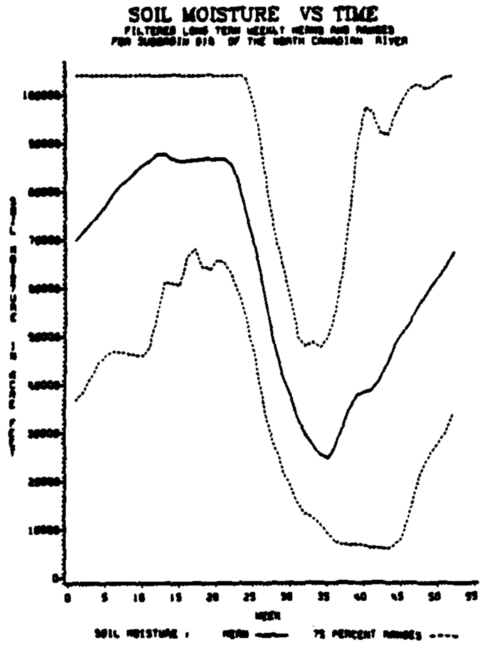


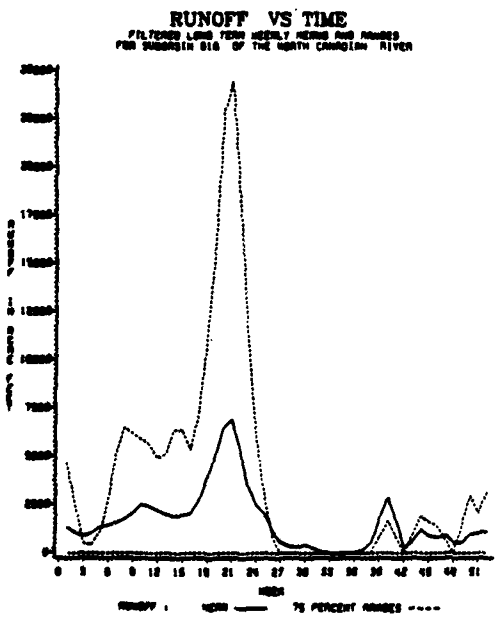

STORAGE, DEMAND VS TIME
1980 DATA ONLY
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
1980 STORAGE:
1980 DEMAND :

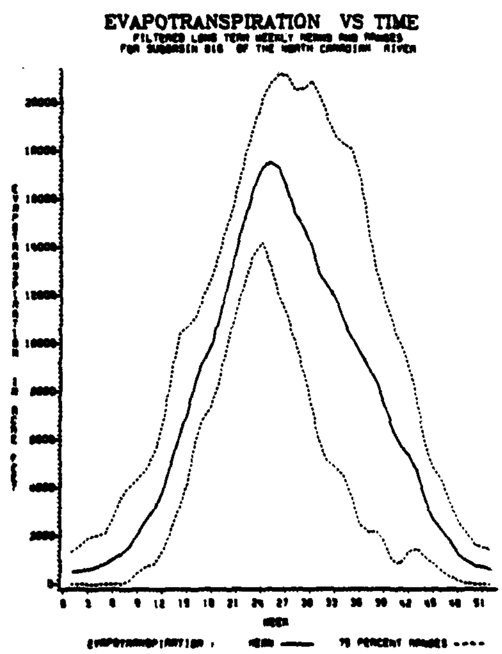

STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1980

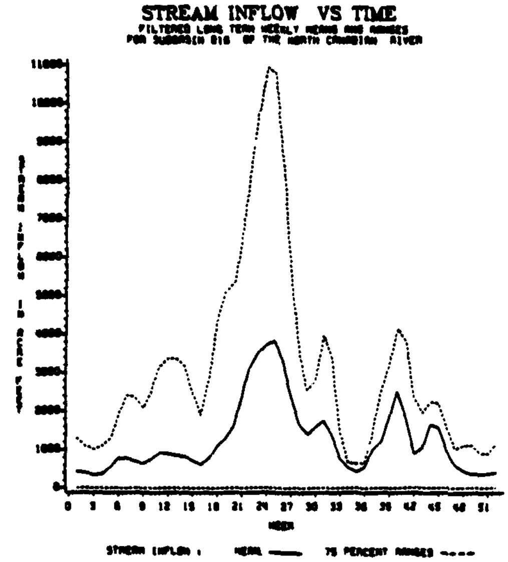

DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 815 OF THE NORTH CANADIAN RIVER
WEEK
DEMAND MEAN 75 PERCENT RANGES
1980

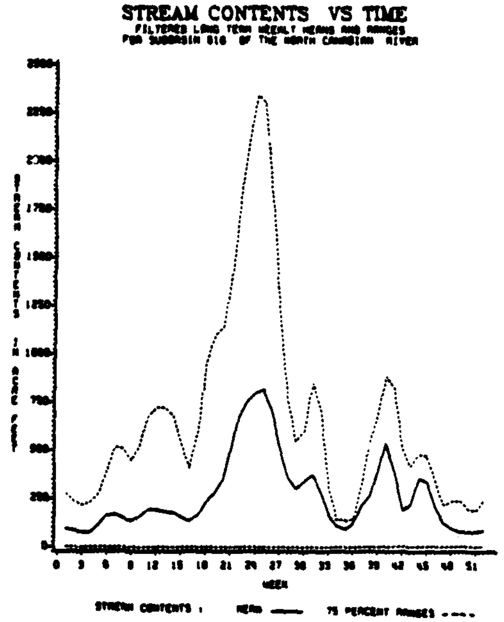

PRECIPITATION VS TIME

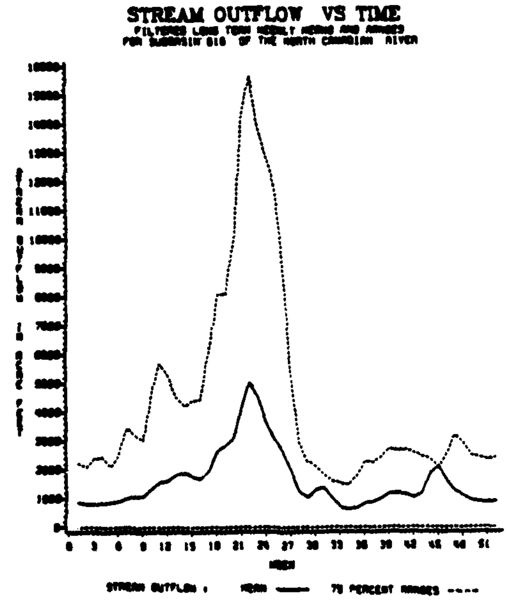

SOIL MOISTURE VS TIME

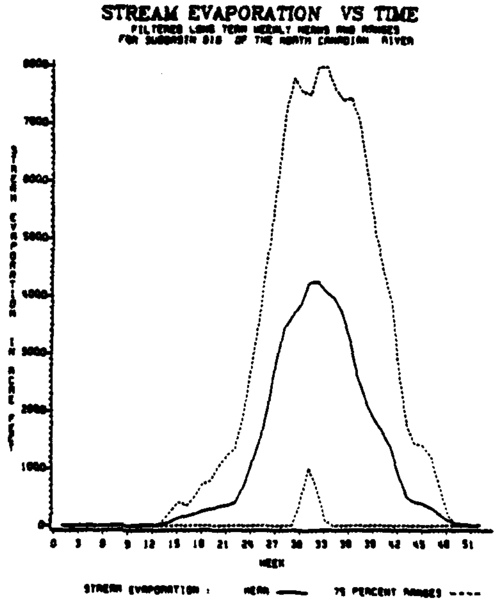

RUNOFF VS TIME

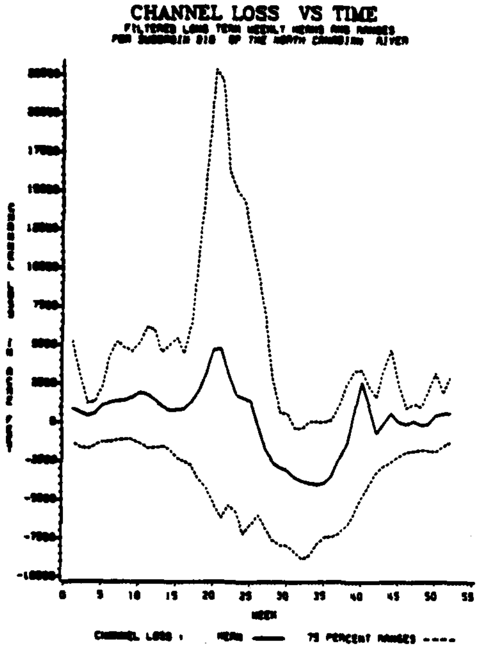

EVAPOTRANSPIRATION VS TIME

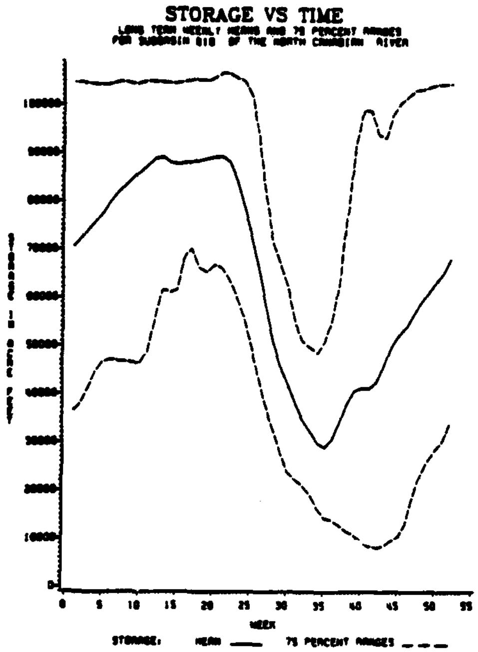

STREAM INFLOW VS TIME

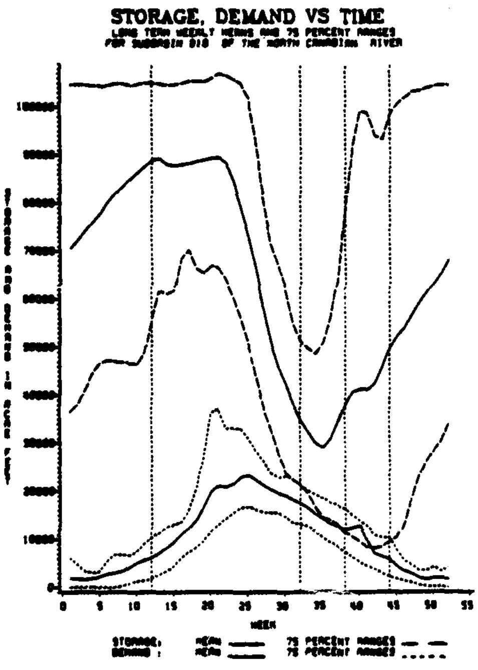

STREAM CONTENTS VS TIME

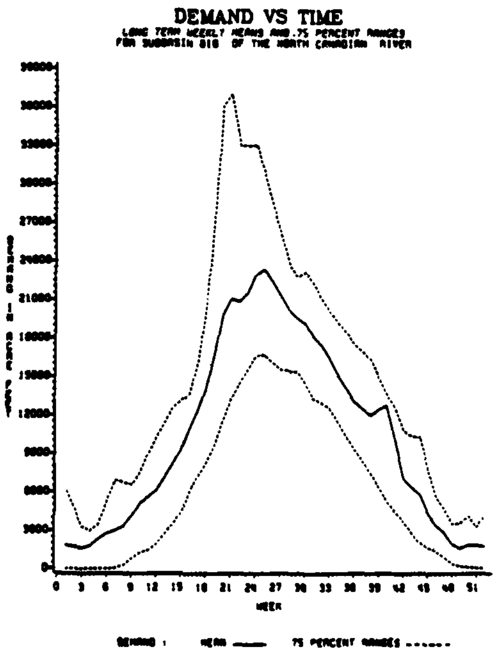

STREAM OUTFLOW VS TIME

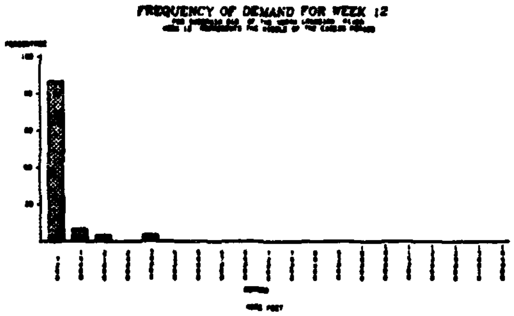

STREAM EVAPORATION VS TIME


CHANNEL LOSS VS TIME


STORAGE VS TIME


STORAGE, DEMAND VS TIME


DEMAND VS TIME



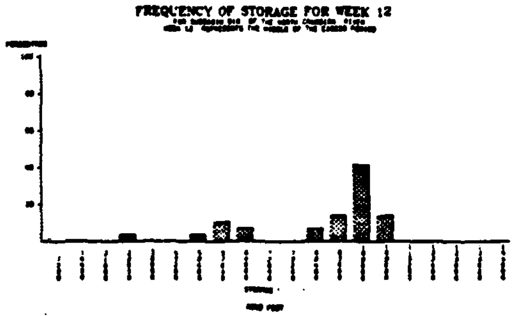
Joint frequency table for subbasin 816, week 12 ([illegible] period).

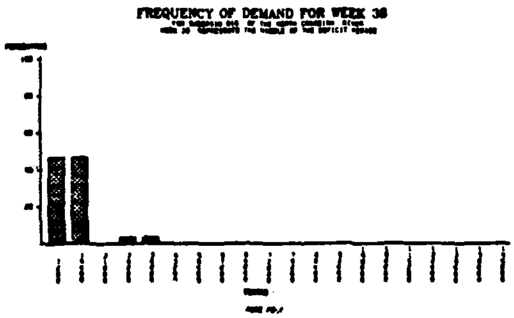
0	0	0	1	0	2	3	
0	0	3	5	10	4	22	2
0	0	0	0	0	5	5	10
0	0	0	0	0	0	0	55
0	0	0	0	0	0	0	88
0	0	0	0	0	0	0	104
2	10	55	88	104			

DEMAND

STORAGE

Storage and demand in thousands of acre feet.





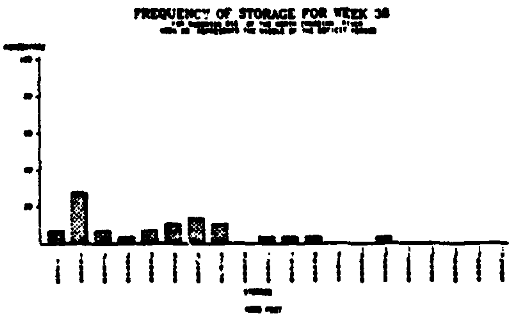
Joint frequency table for subbasin 816, week 38 (mid-deficit period).

0	2	2	1	1	0	6	
0	2	3	4	4	0	13	8
0	0	0	2	4	1	7	12
0	0	0	0	3	1	4	47
0	0	0	0	0	0	0	38
0	0	0	0	0	0	0	77
0	4	5	7	12	2	30	
8	12	17	38	77			

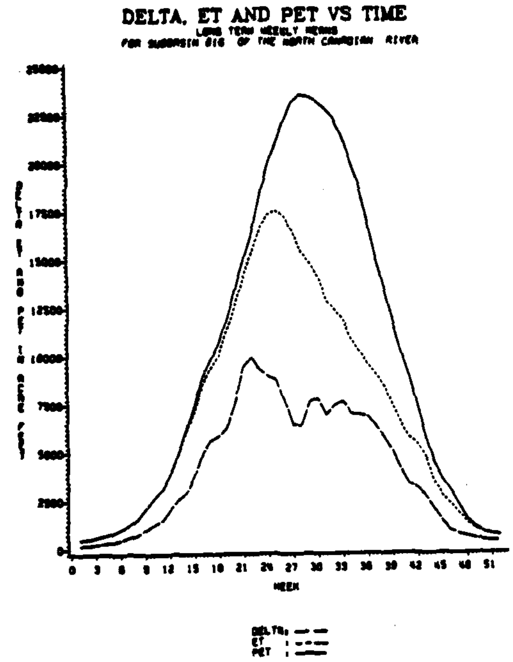
DEMAND

STORAGE

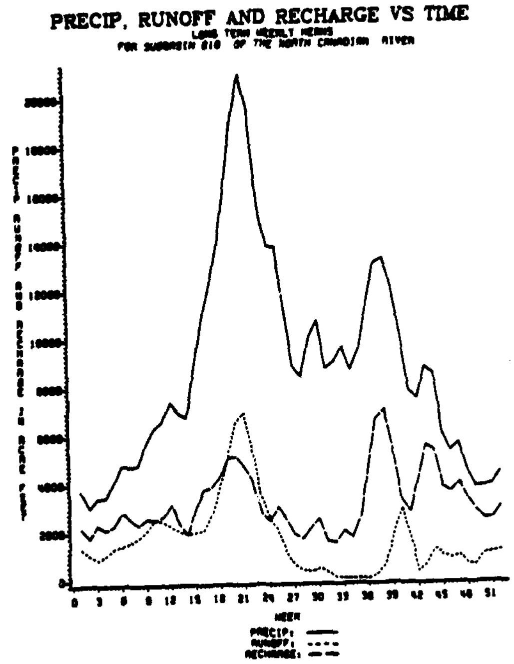
Storage and demand in thousands of acre feet.

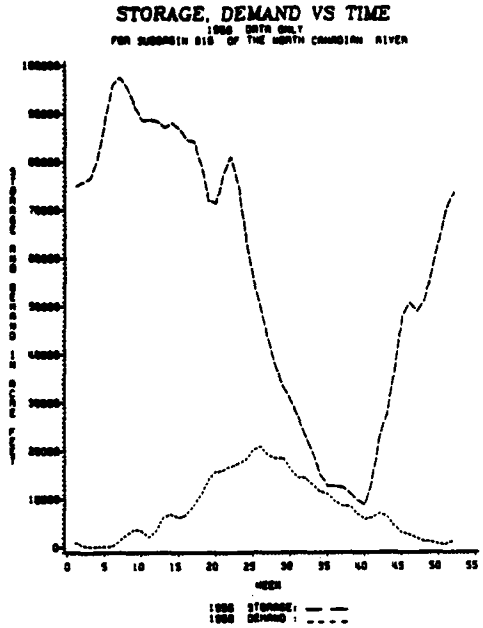


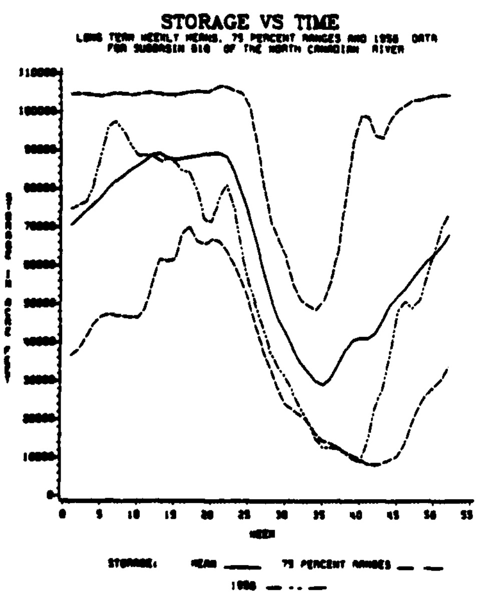
DELTA, ET AND PET VS TIME

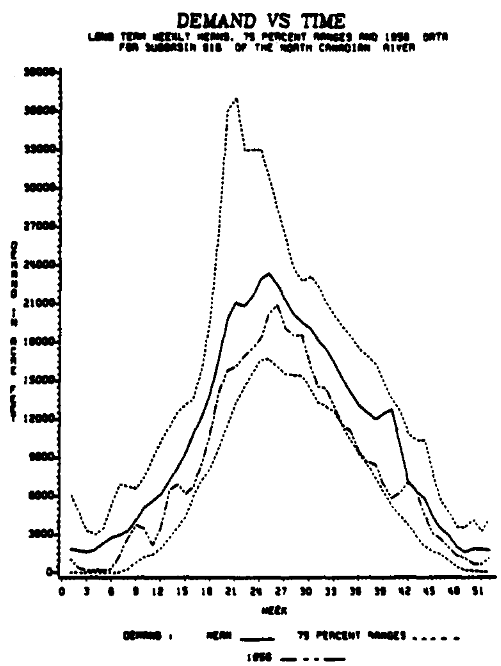


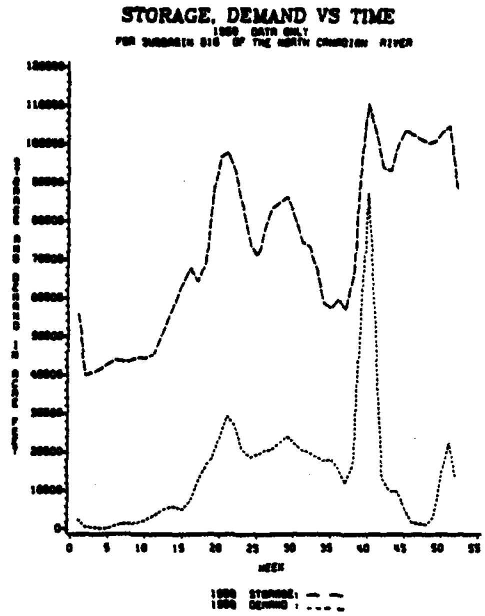
PRECIP, RUNOFF AND RECHARGE VS TIME

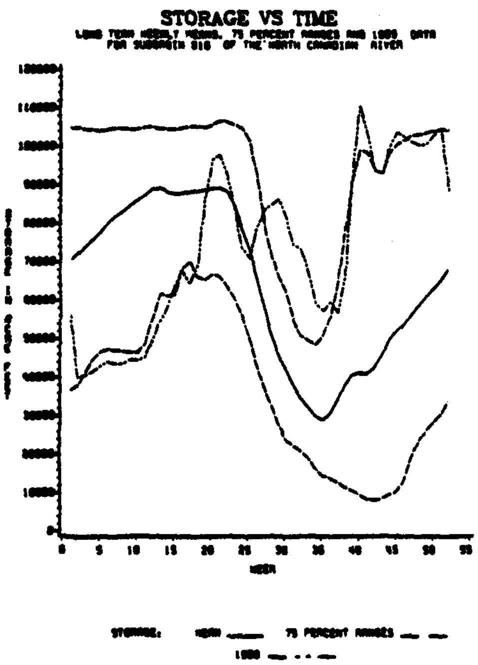


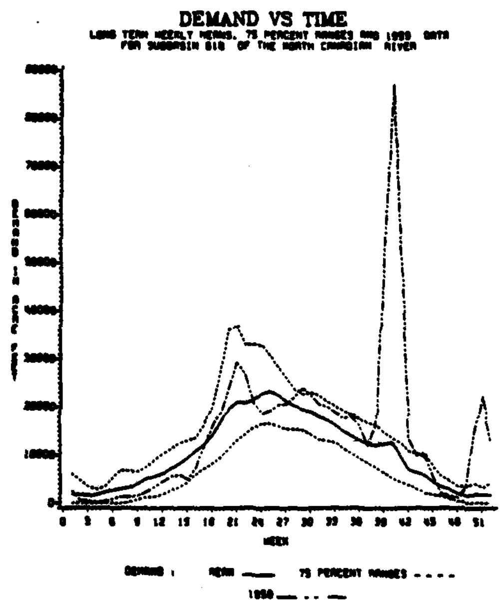

STORAGE, DEMAND VS TIME

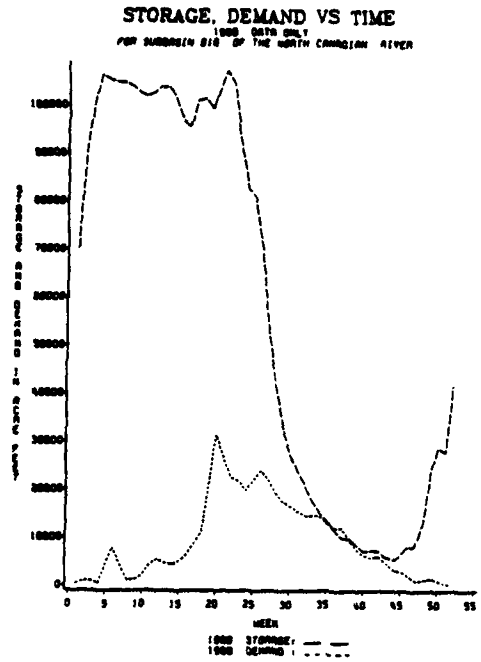

STORAGE VS TIME

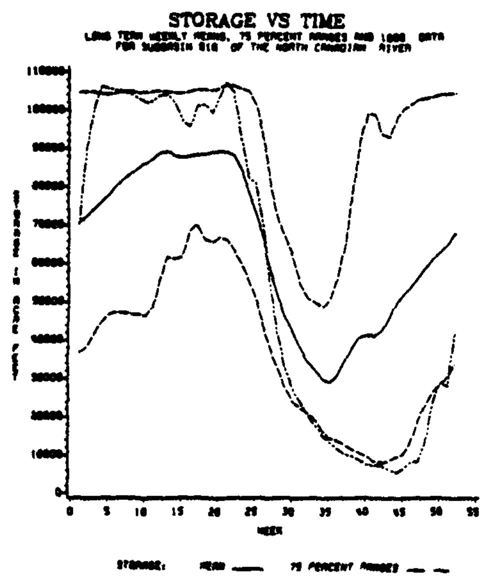

DEMAND VS TIME

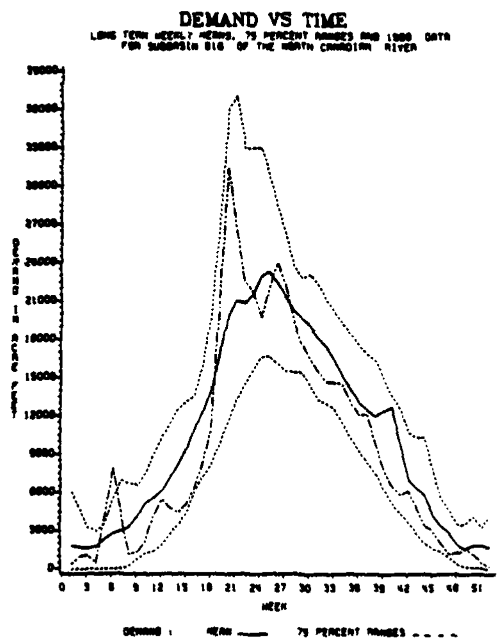

STORAGE, DEMAND VS TIME

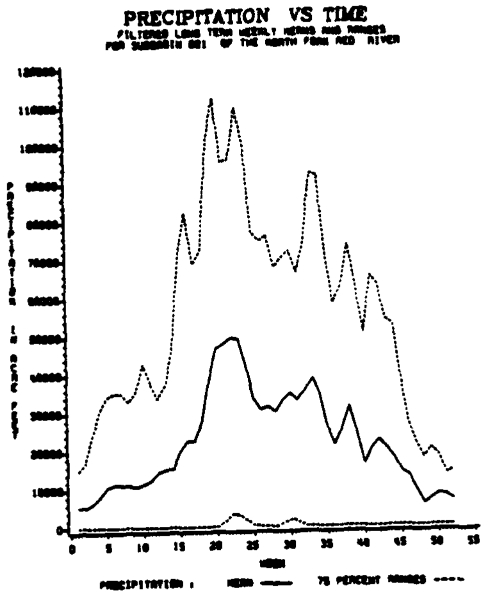

STORAGE VS TIME

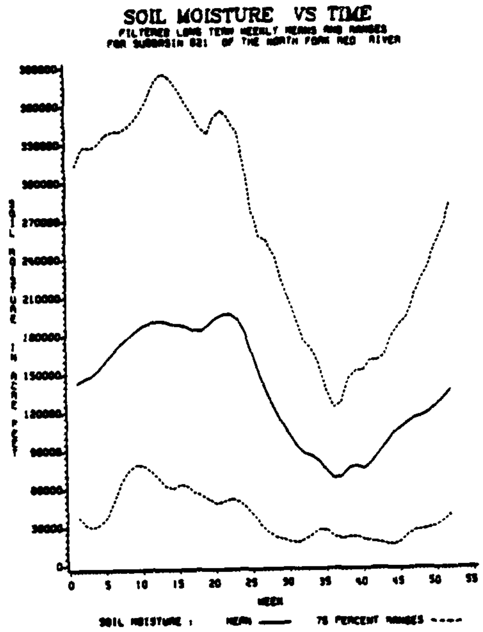

DEMAND VS TIME

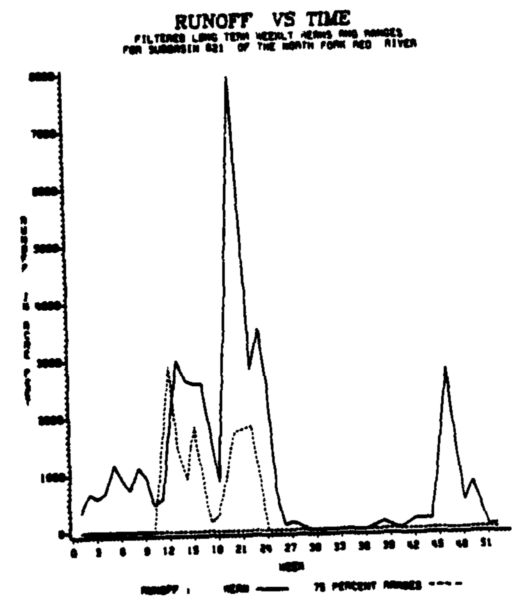

STORAGE, DEMAND VS TIME

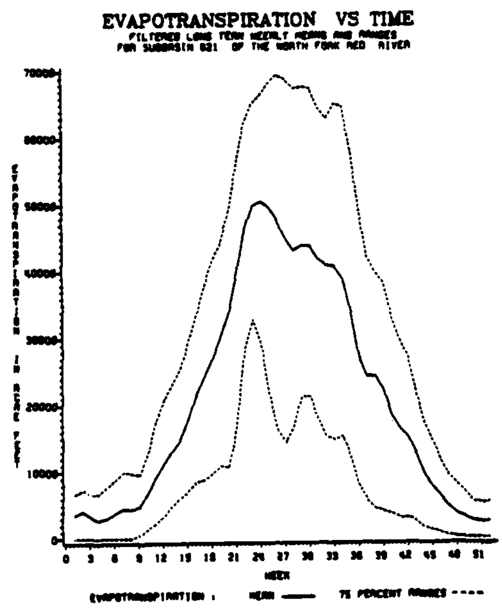

STORAGE VS TIME


DEMAND VS TIME

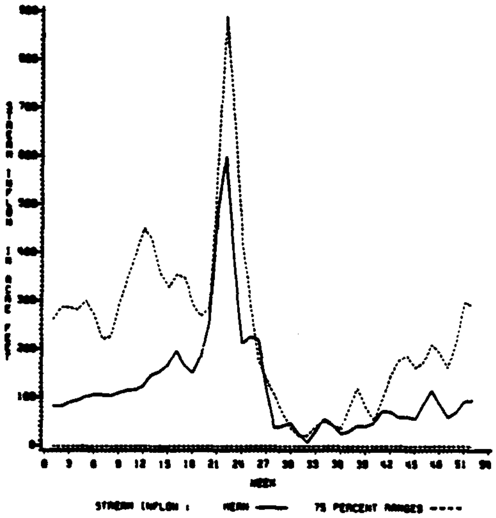

PRECIPITATION VS TIME


SOIL MOISTURE VS TIME

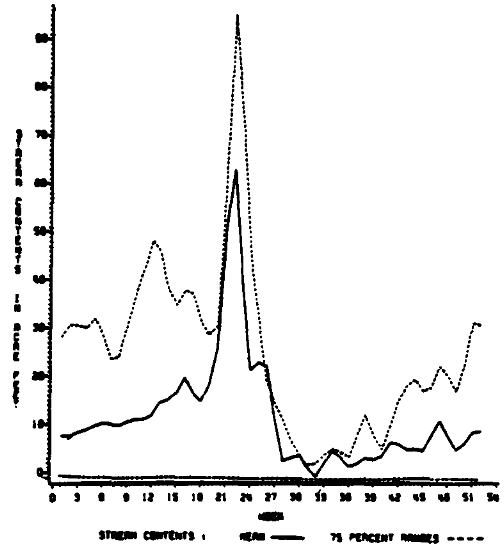

RUNOFF VS TIME


EVAPOTRANSPIRATION VS TIME

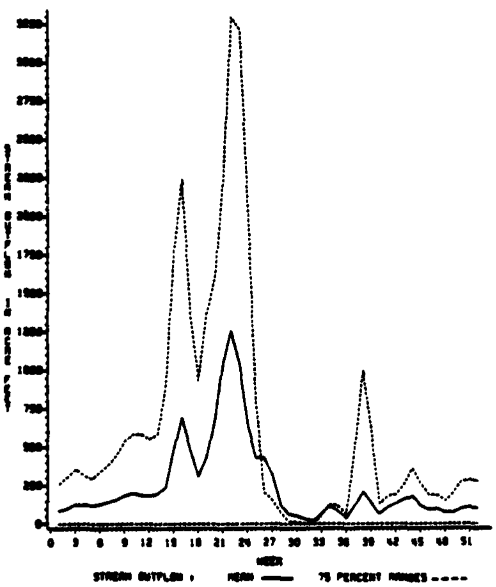
STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 801 OF THE NORTH FORK RED RIVER



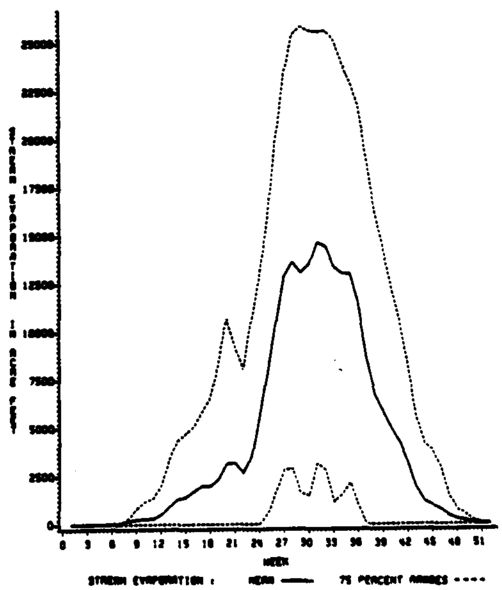
STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 801 OF THE NORTH FORK RED RIVER

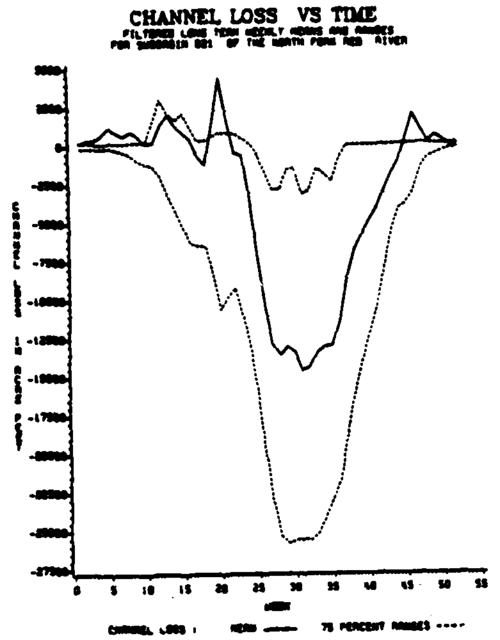


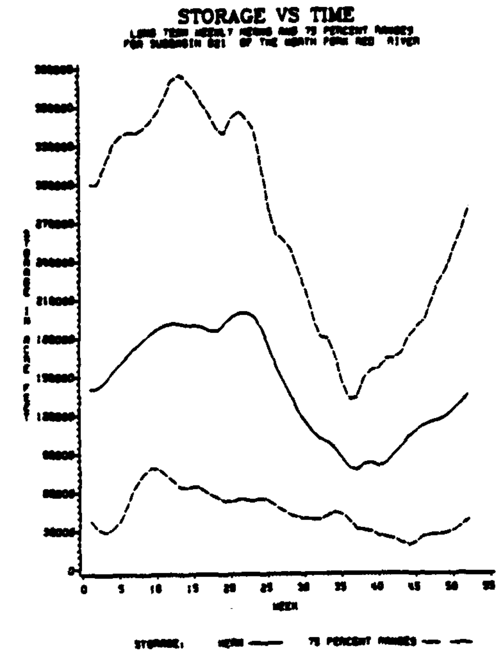
STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 801 OF THE NORTH FORK RED RIVER

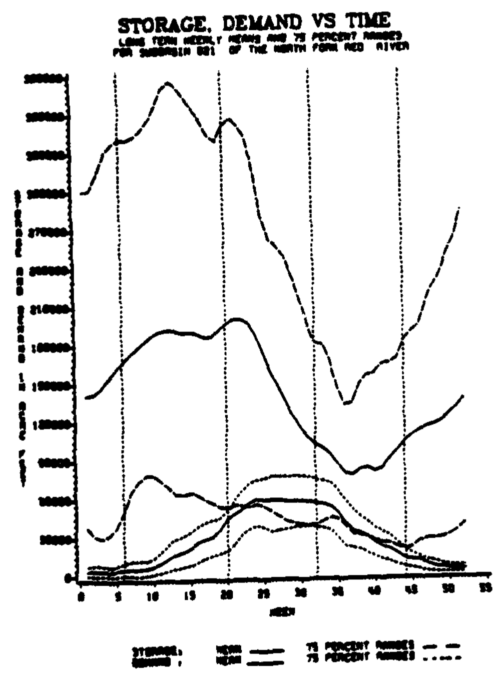


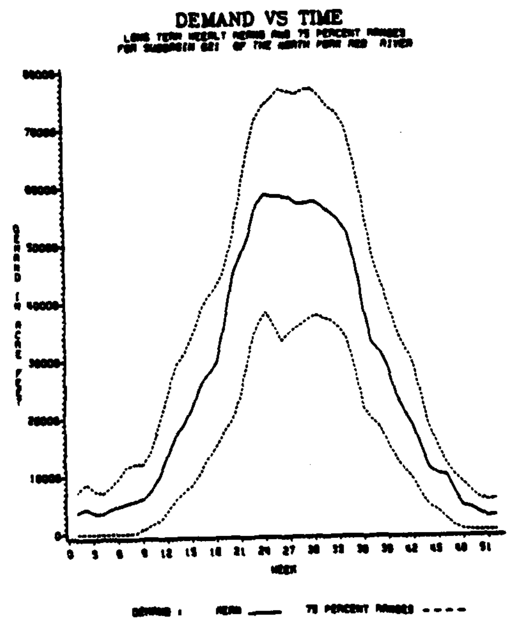
STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 801 OF THE NORTH FORK RED RIVER




CHANNEL LOSS VS TIME


STORAGE VS TIME


STORAGE, DEMAND VS TIME


DEMAND VS TIME

Joint frequency table for subbasin B21, week 6
(mid-surplus period).

0	0	2	3	3	2	10	
0	0	1	11	5	1	18	1
0	0	1	0	0	1	2	10
0	0	0	0	0	0	0	50
0	0	0	0	0	0	0	165
0	0	0	0	0	0	0	340
0	0	4	14	8	4	30	

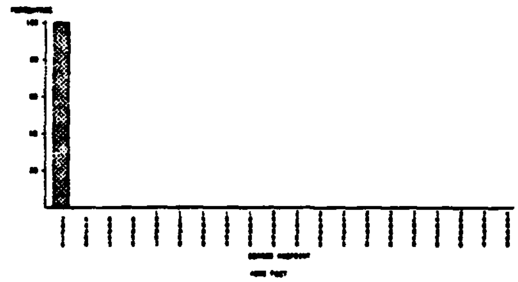
1 10 50 165 340

STORAGE

DEMAND

Storage and demand in thousands of acre feet.

FREQUENCY OF DEMAND FOR WEEK 6



FREQUENCY OF STORAGE FOR WEEK 6

Joint frequency table for subbasin B21, week 32
(mid-deficit period).

3	0	0	1	0	0	4	
0	0	0	0	0	0	0	40
1	0	9	3	9	1	23	44
0	0	0	0	2	1	3	75
0	0	0	0	0	0	0	100
0	0	0	0	0	0	0	180
4	0	9	4	11	2	30	

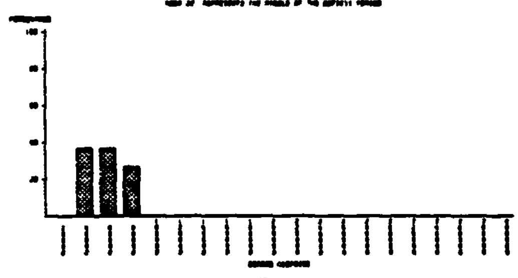
40 44 75 100 180

STORAGE

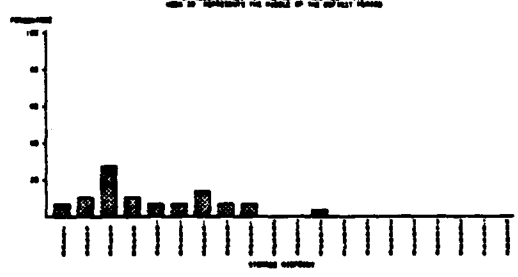
DEMAND

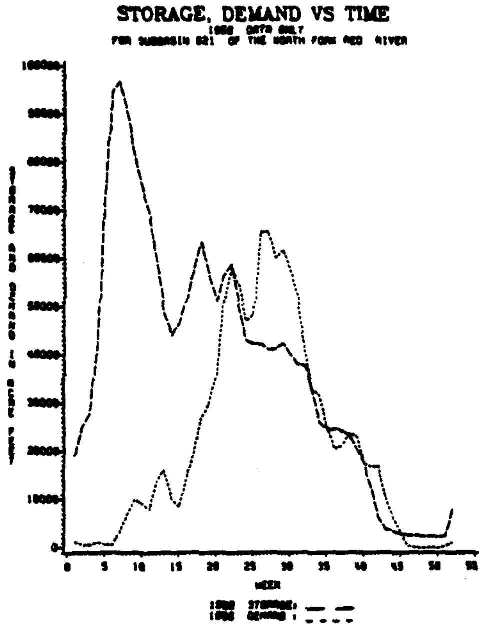
Storage and demand in thousands of acre feet.

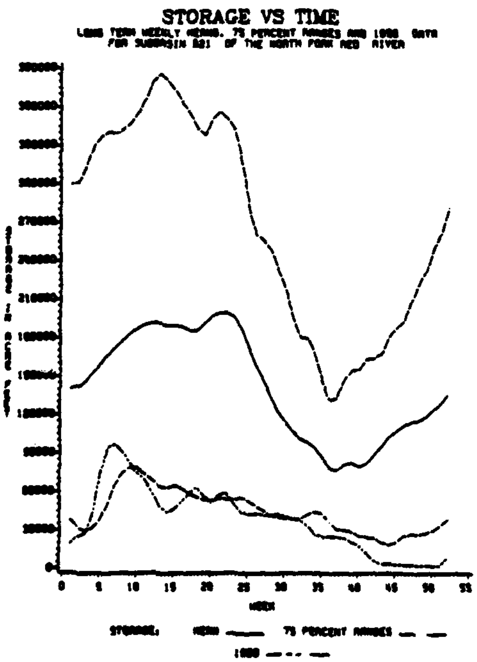
FREQUENCY OF DEMAND FOR WEEK 32

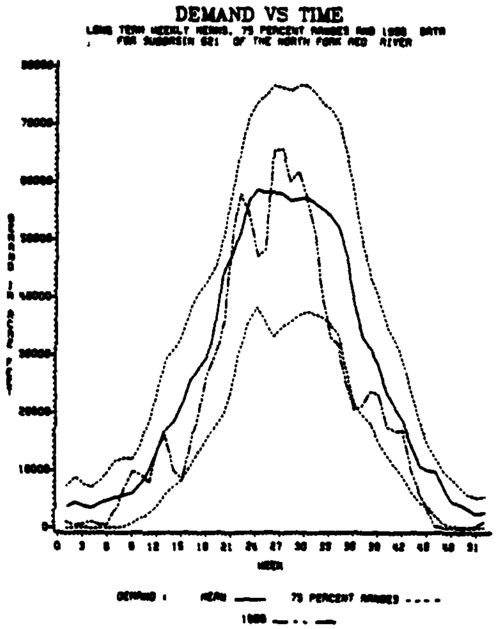


FREQUENCY OF STORAGE FOR WEEK 32

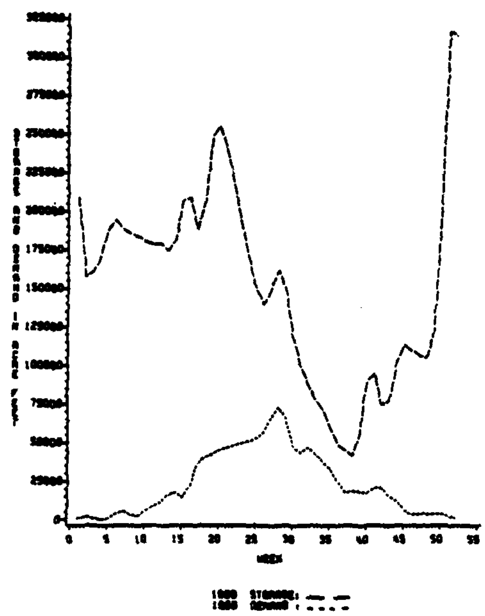



STORAGE, DEMAND VS TIME

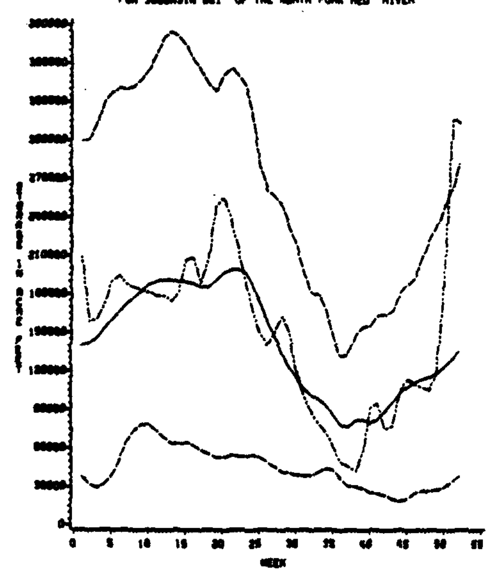

STORAGE VS TIME


DEMAND VS TIME

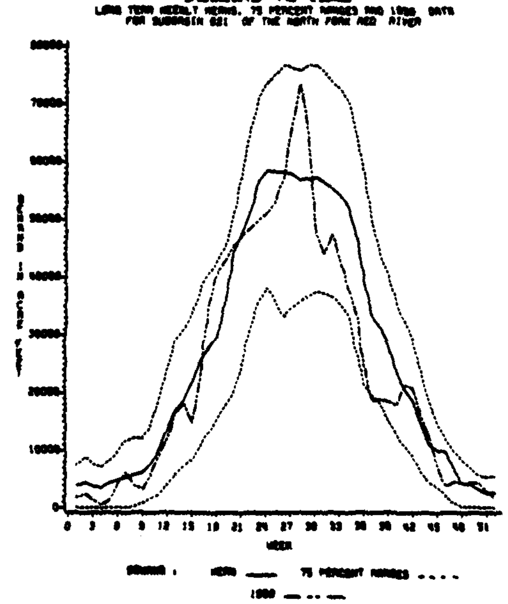
STORAGE, DEMAND VS TIME



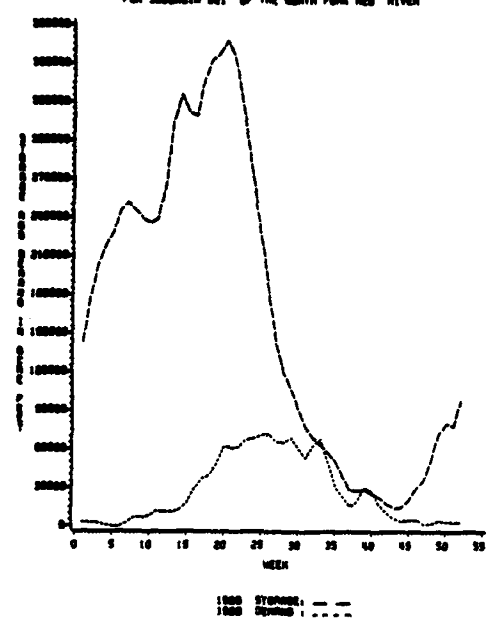
STORAGE VS TIME



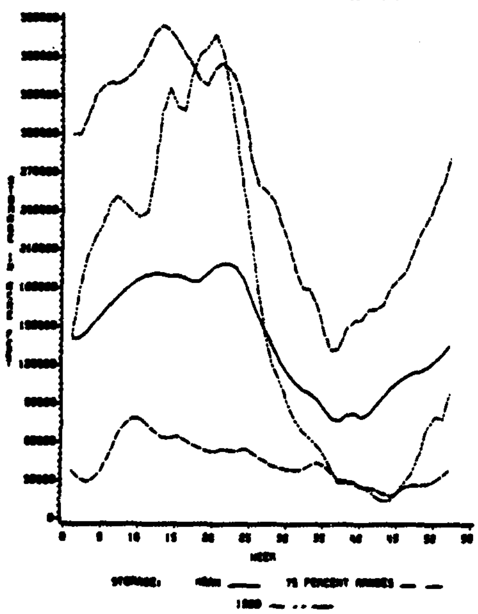
DEMAND VS TIME



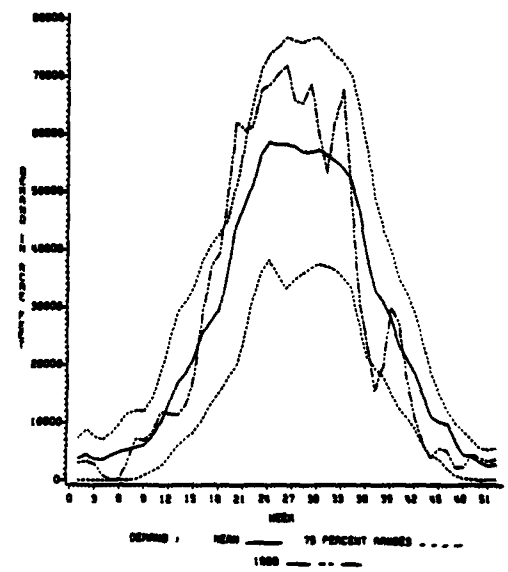
STORAGE, DEMAND VS TIME



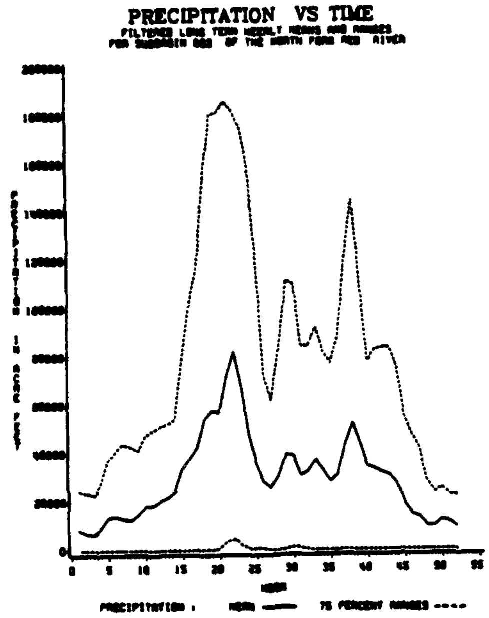
STORAGE VS TIME



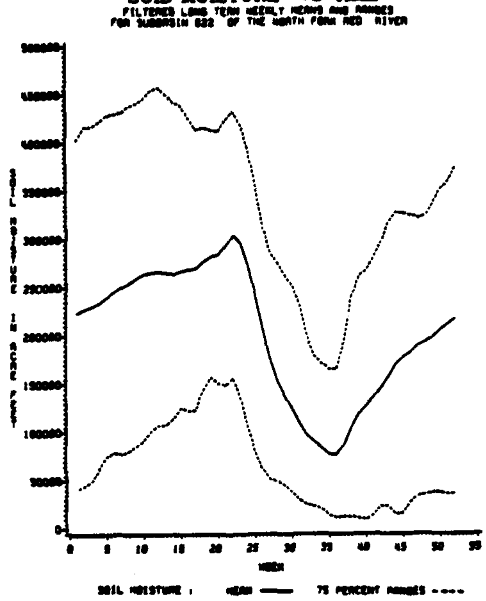
DEMAND VS TIME



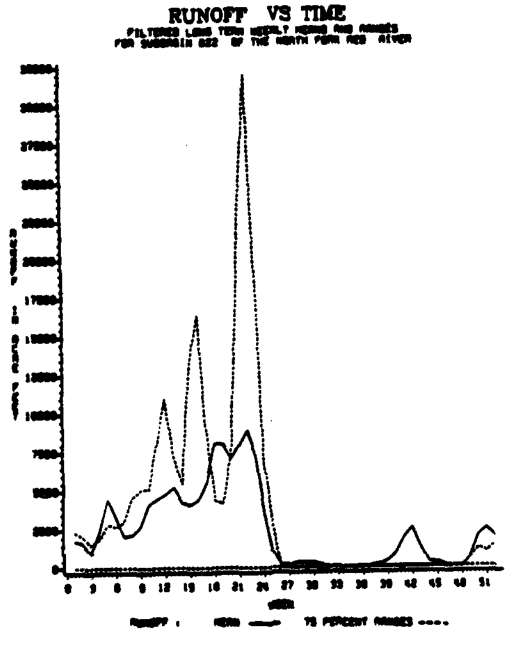
PRECIPITATION VS TIME



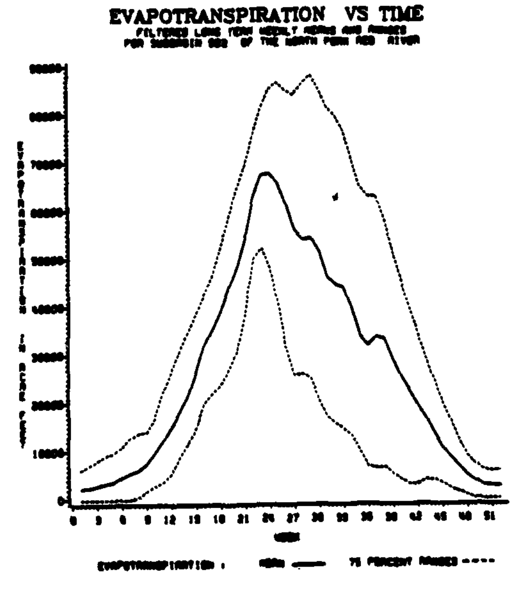
SOIL MOISTURE VS TIME

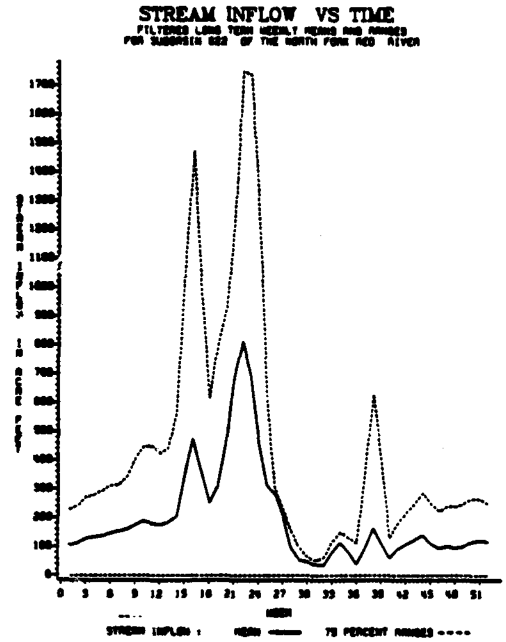


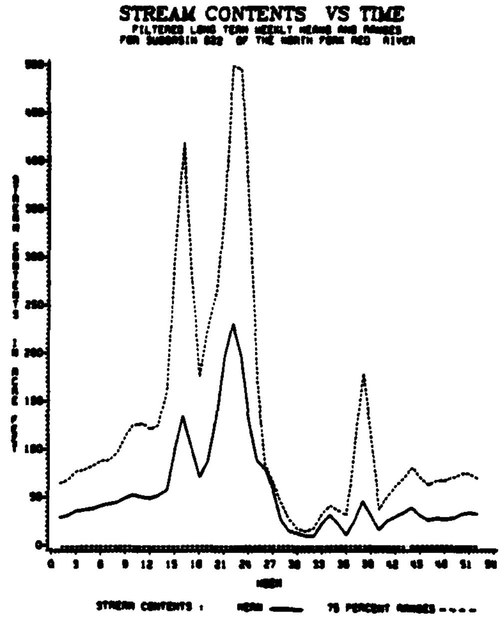
RUNOFF VS TIME

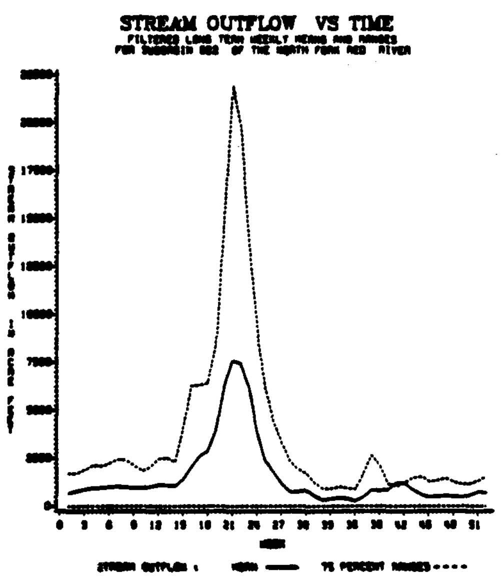


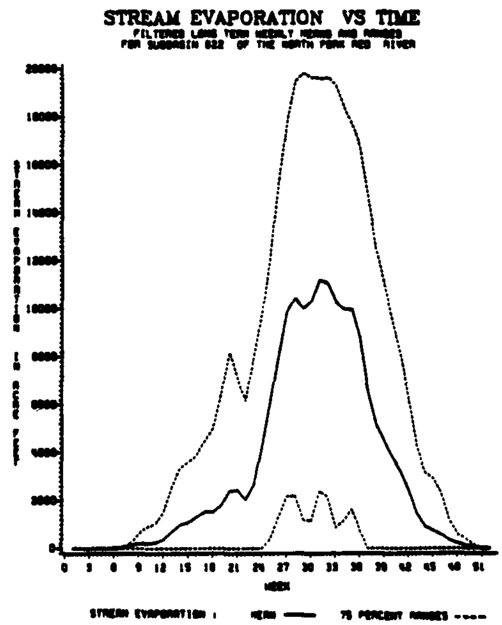
EVAPOTRANSPIRATION VS TIME

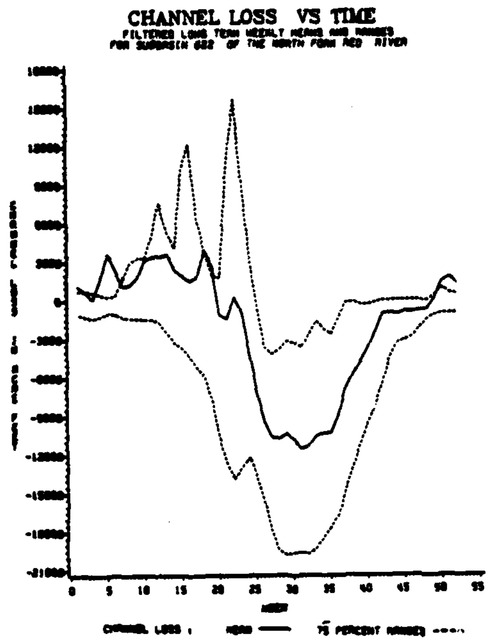


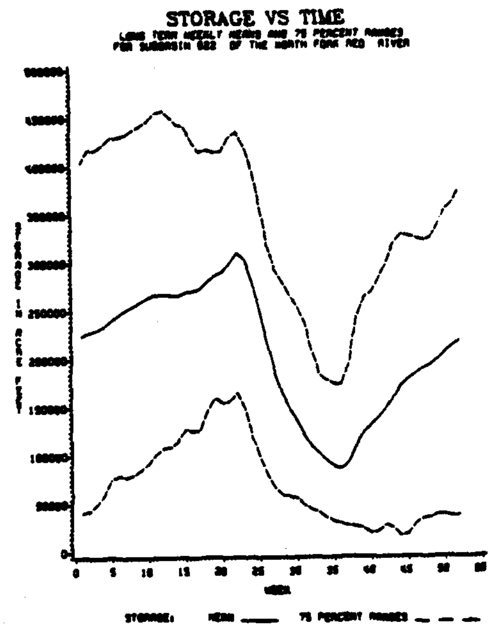

STREAM INFLOW VS TIME

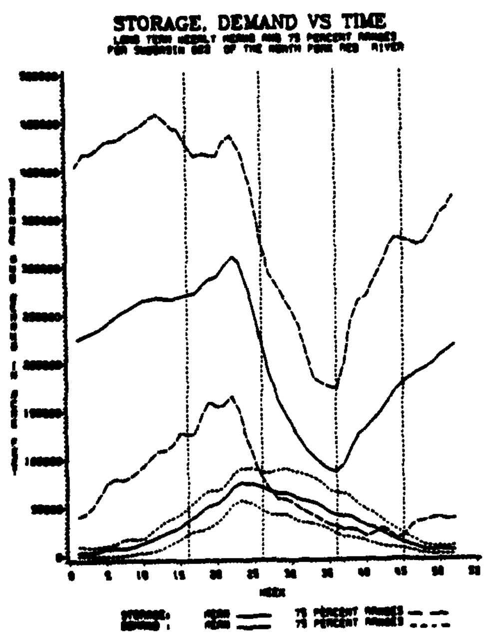

STREAM CONTENTS VS TIME

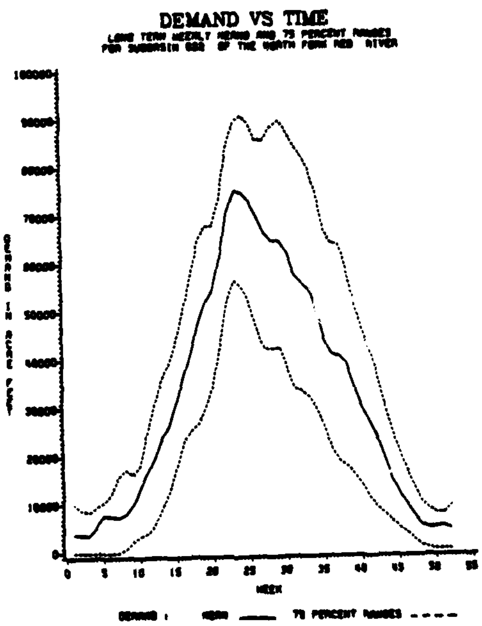

STREAM OUTFLOW VS TIME


STREAM EVAPORATION VS TIME

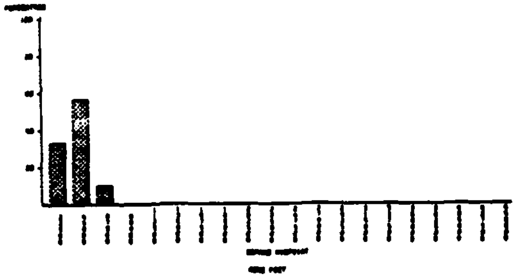

CHANNEL LOSS VS TIME


STORAGE VS TIME

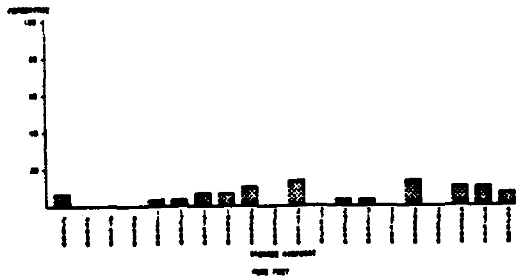

STORAGE, DEMAND VS TIME


DEMAND VS TIME

FREQUENCY OF DEMAND FOR WEEK 16



FREQUENCY OF STORAGE FOR WEEK 16



Joint frequency table for subbasin B22, week 16 (mid-excess period).

0	0	0	1	0	0	1	
0	2	1	12	6	2	23	20
0	0	0	0	4	2	6	50
0	0	0	0	0	0	0	125
0	0	0	0	0	0	0	270
0	0	0	0	0	0	0	425
0	2	1	13	10	4	30	

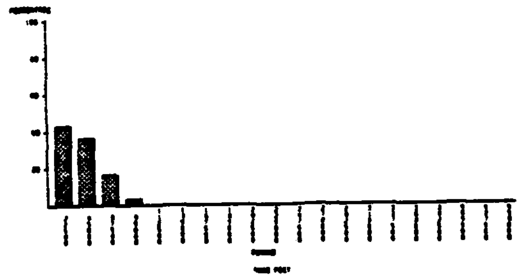
DEMAND

20 50 125 270 425

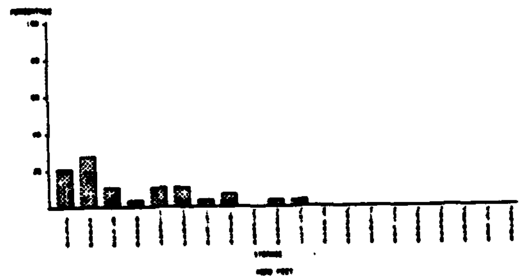
STORAGE

Storage and demand in thousands of acre feet.

FREQUENCY OF DEMAND FOR WEEK 36



FREQUENCY OF STORAGE FOR WEEK 36



Joint frequency table for subbasin B22, week 36 (mid-deficit period).

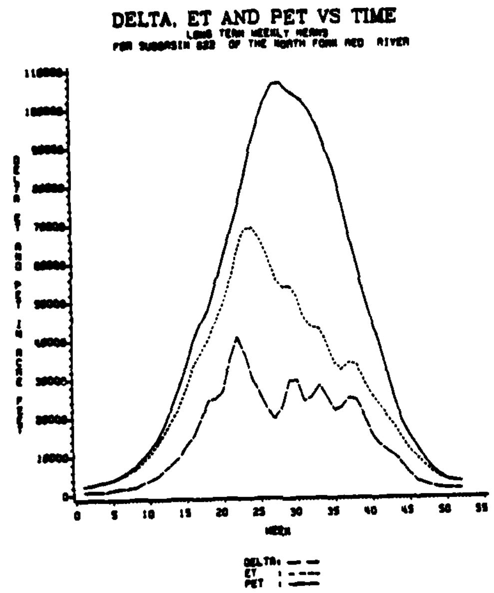
0	2	3	0	0	0	5	
0	1	5	0	0	0	6	20
1	0	4	2	6	4	17	30
0	0	0	0	1	0	1	65
0	0	0	0	1	0	1	85
0	0	0	0	0	0	0	170
1	3	12	2	7	4	30	

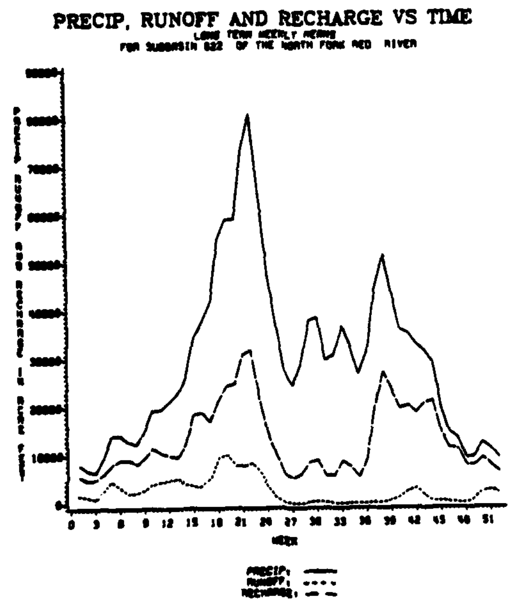
DEMAND

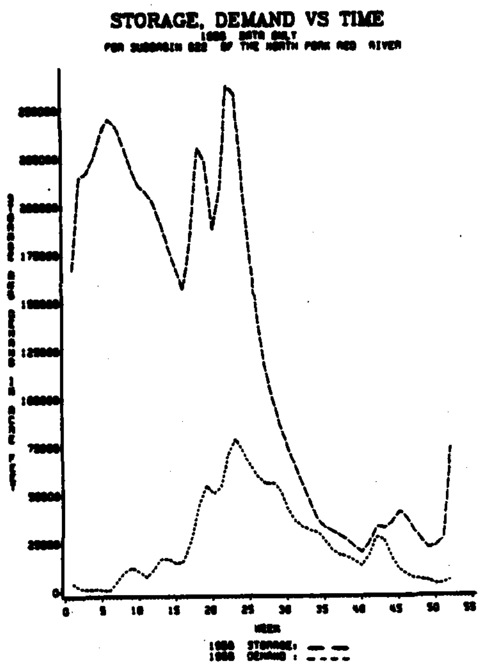
20 30 65 85 170

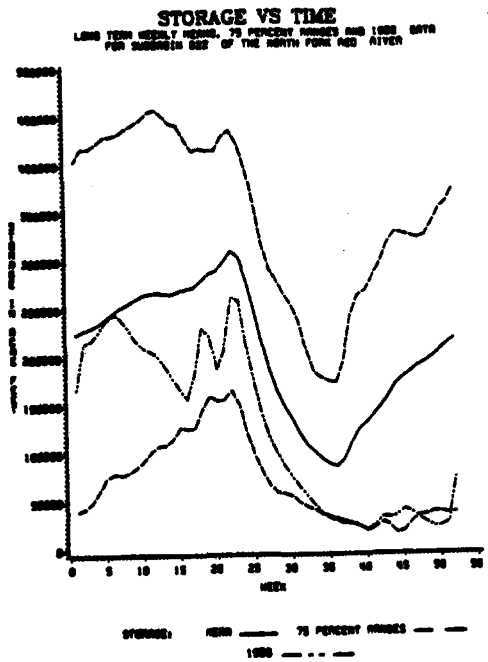
STORAGE

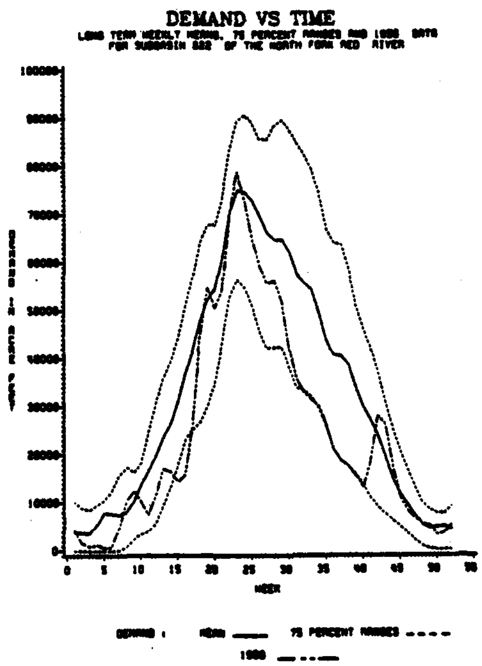
Storage and demand in thousands of acre feet.


DELTA, ET AND PET VS TIME
LONG TERM WEEKLY MEANS
FOR SUBBASIN 822 OF THE NORTH FORK RED RIVER
WEEK
DELTA
ET
PET

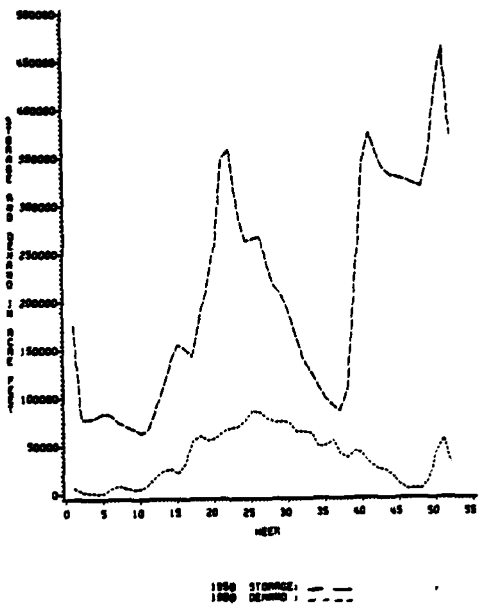

PRECIP, RUNOFF AND RECHARGE VS TIME
LONG TERM WEEKLY MEANS
FOR SUBBASIN 822 OF THE NORTH FORK RED RIVER
WEEK
PRECIP
RUNOFF
RECHARGE


STORAGE, DEMAND VS TIME

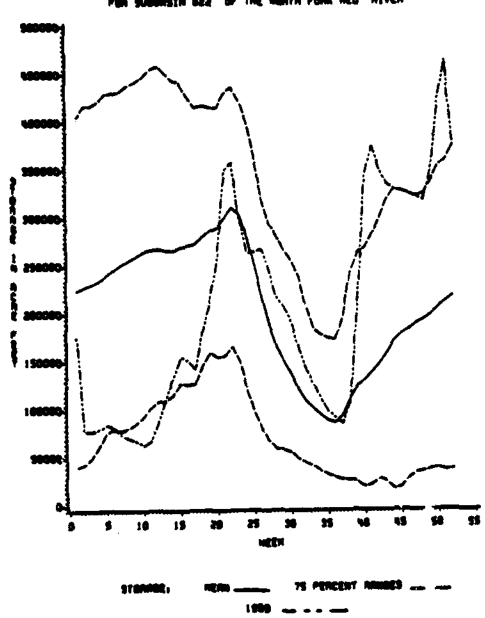

STORAGE VS TIME


DEMAND VS TIME

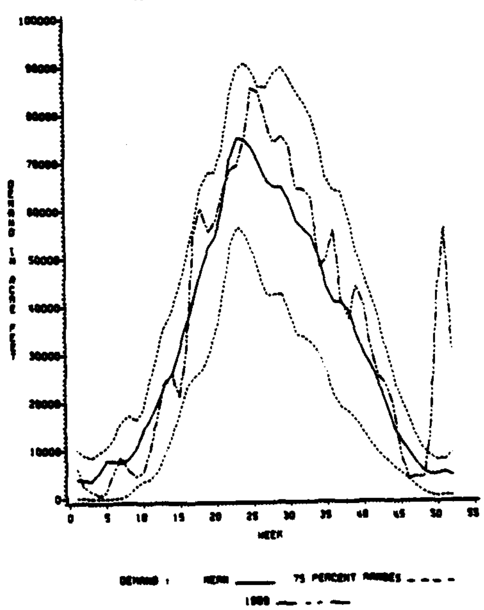
STORAGE, DEMAND VS TIME



STORAGE VS TIME



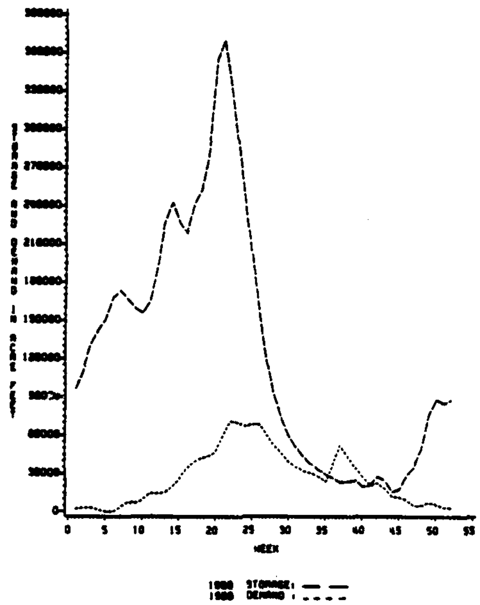
DEMAND VS TIME



STORAGE, DEMAND VS TIME

1980 DATA ONLY

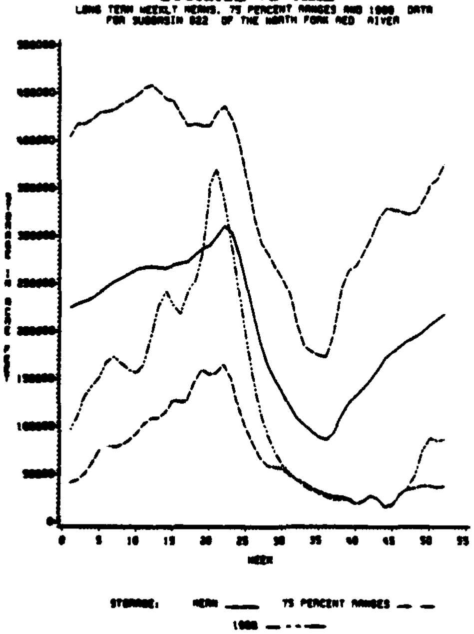
FOR SUBBASIN 622 OF THE NORTH FORK RED RIVER



STORAGE VS TIME

LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA

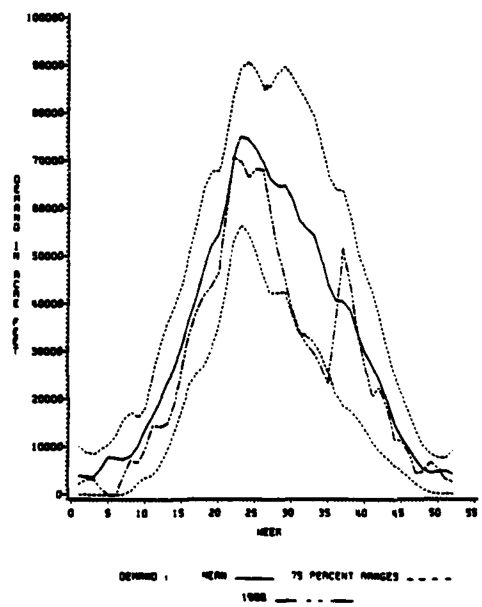
FOR SUBBASIN 622 OF THE NORTH FORK RED RIVER



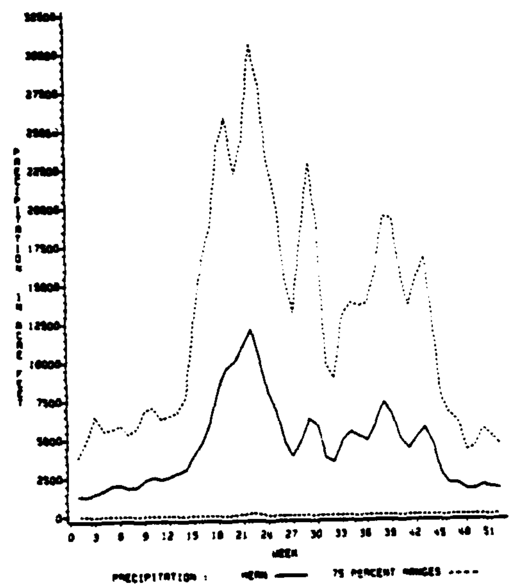
DEMAND VS TIME

LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA

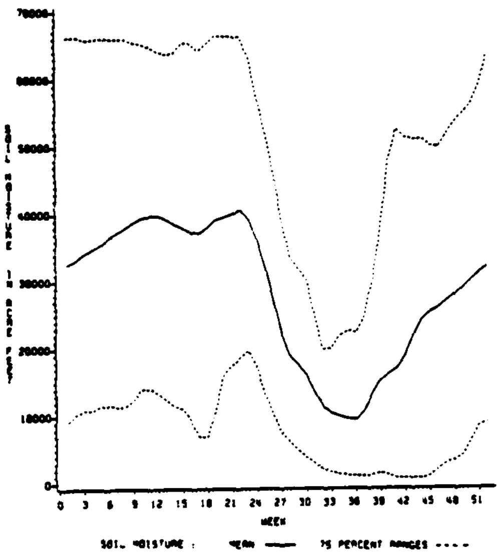
FOR SUBBASIN 622 OF THE NORTH FORK RED RIVER



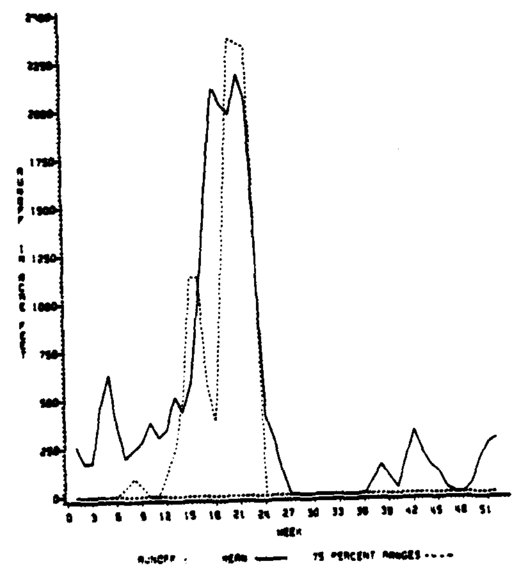
PRECIPITATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 623 OF THE NORTH FORK RED RIVER



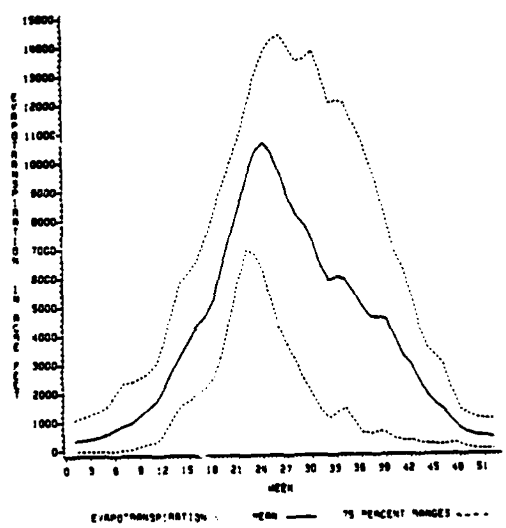
SOIL MOISTURE VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 623 OF THE NORTH FORK RED RIVER



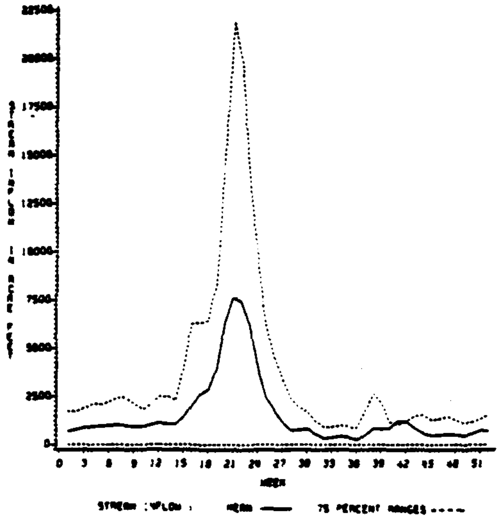
RUNOFF VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 623 OF THE NORTH FORK RED RIVER



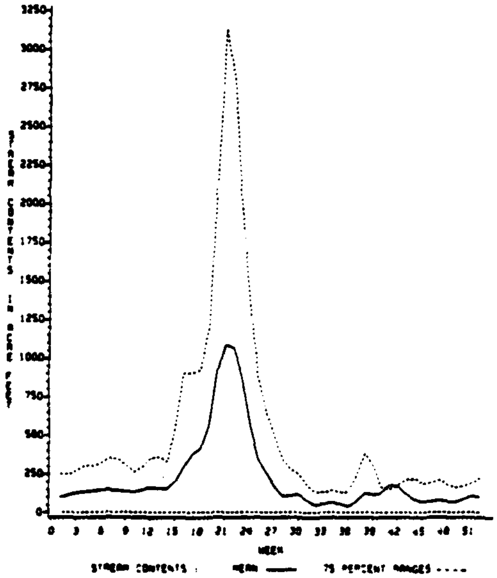
EVAPOTRANSPIRATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 623 OF THE NORTH FORK RED RIVER



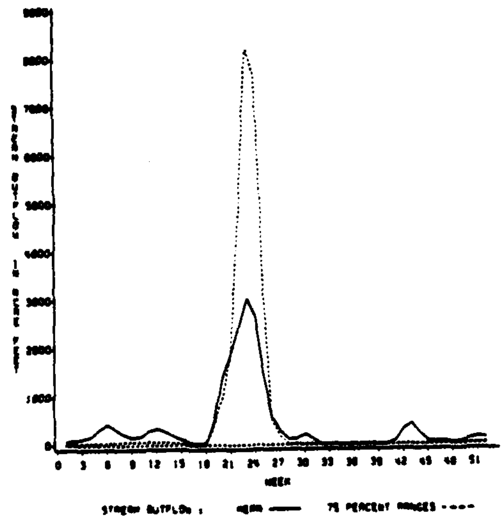
STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 523 OF THE NORTH FORK RED RIVER



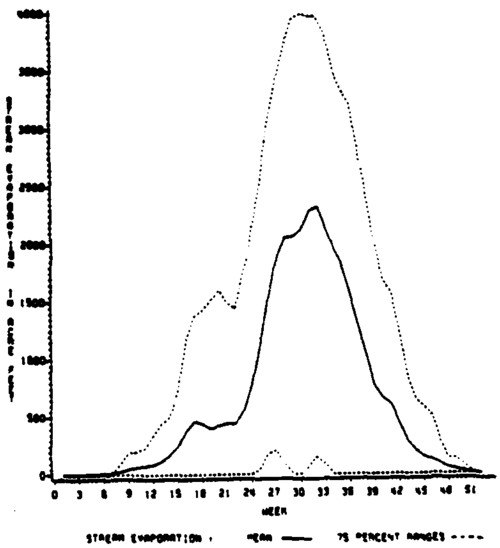
STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 523 OF THE NORTH FORK RED RIVER

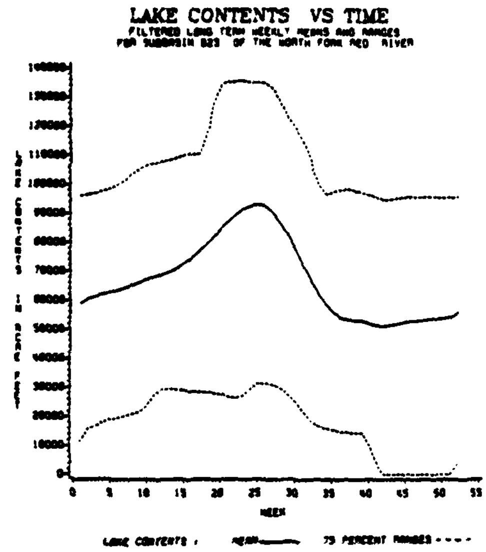


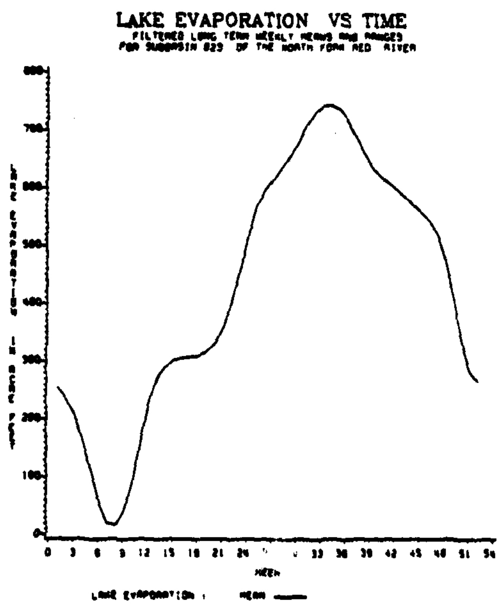
STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 523 OF THE NORTH FORK RED RIVER

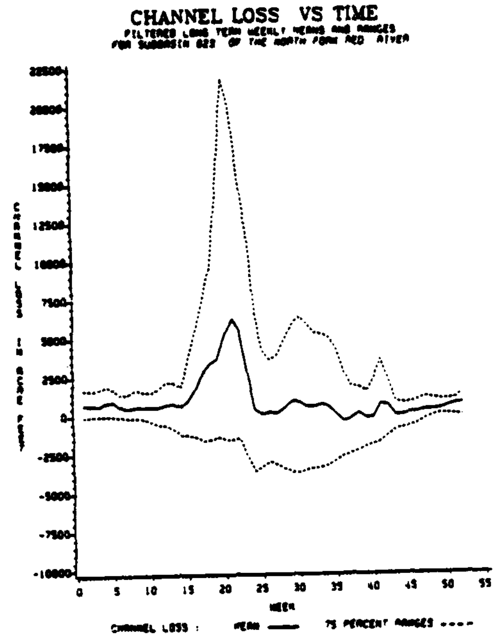


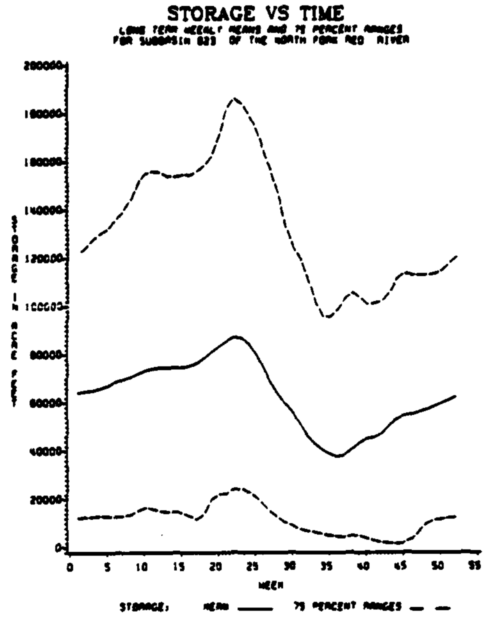
STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 523 OF THE NORTH FORK RED RIVER

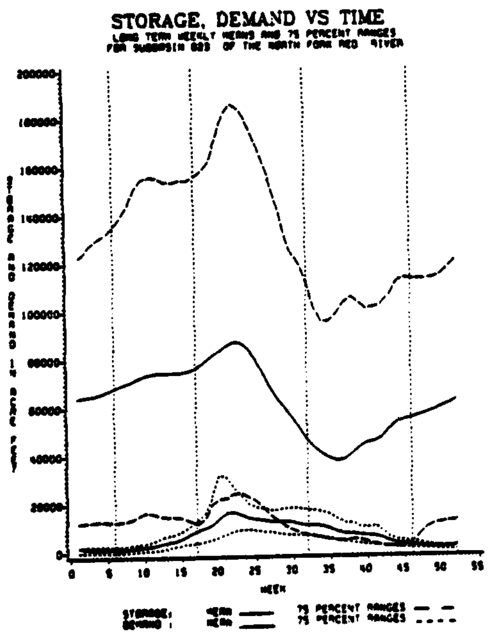


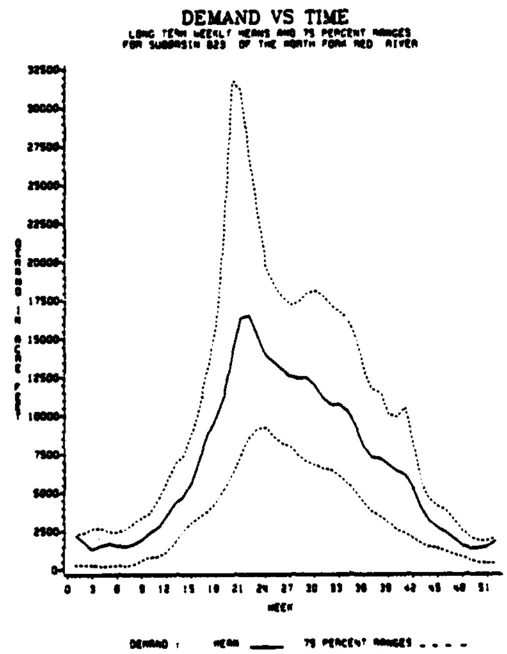

LAKE CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER
WEEK
LAKE CONTENTS : MEAN 75 PERCENT RANGES

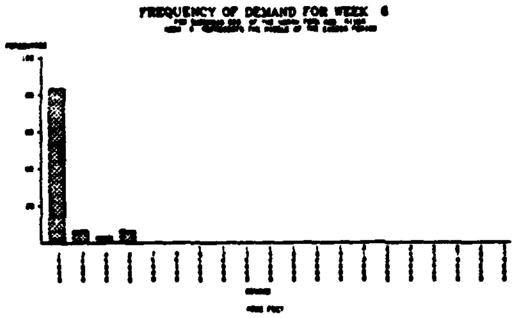

LAKE EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER
WEEK
LAKE EVAPORATION : MEAN


CHANNEL LOSS VS TIME


STORAGE VS TIME


STORAGE, DEMAND VS TIME


DEMAND VS TIME



Joint frequency table for subbasin B23, week 6 (mid-season period).

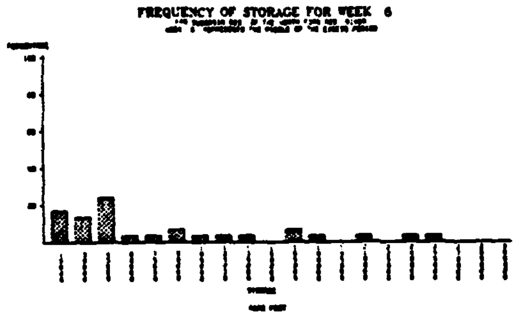
0	0	0	7	5	6	16	
0	0	1	3	0	3	7	1
0	0	3	2	0	0	5	2
0	0	0	0	0	0	0	12
0	0	0	0	0	0	0	68
0	0	0	0	0	0	0	136
0	0	4	12	5	9	30	

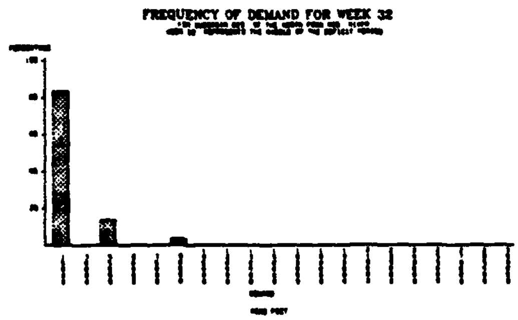
DEMAND

1 2 12 68 136

STORAGE

Storage and demand in thousands of acre feet.





Joint frequency table for subbasin B23, week 32 (mid-deficit period).

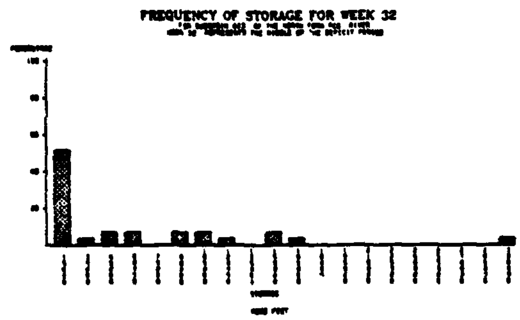
1	0	2	0	0	0	3	
0	0	0	0	0	0	0	6
1	0	8	5	3	3	20	8
0	0	0	2	2	1	5	18
0	0	0	0	2	0	2	46
0	0	0	0	0	0	0	110
2	0	10	7	5	4	30	

DEMAND

6 8 18 46 110

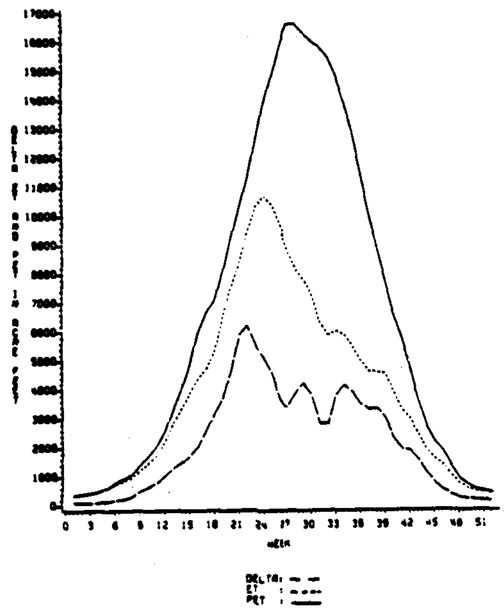
STORAGE

Storage and demand in thousands of acre feet.



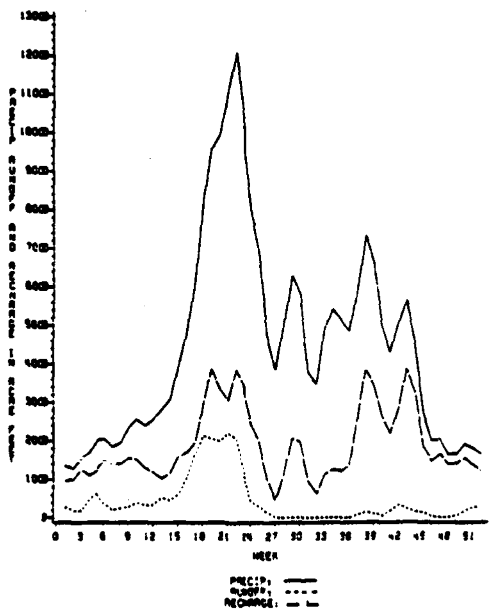
DELTA, ET AND PET VS TIME

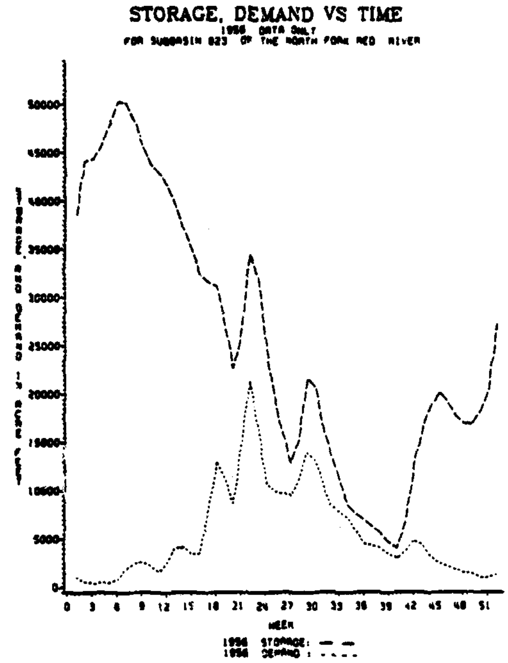
LONG TERM WEEKLY MEANS
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER

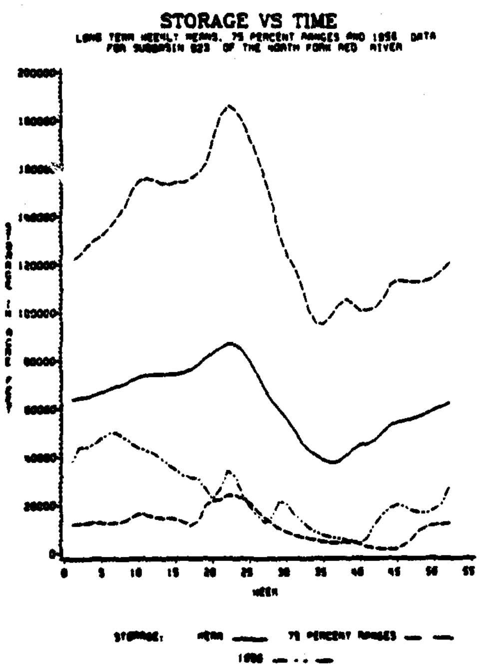


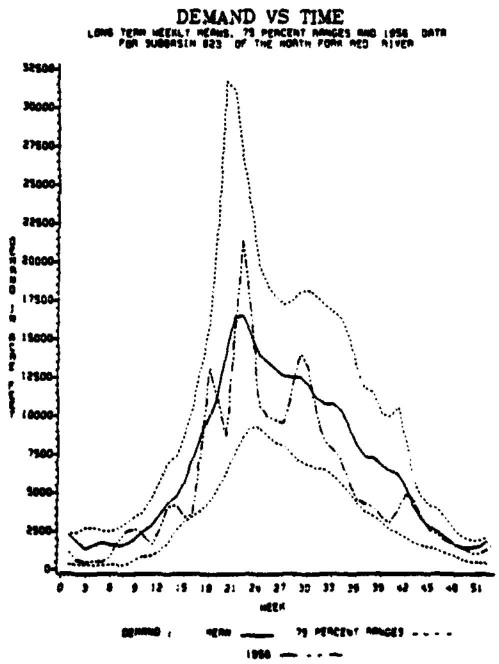
PRECIP, RUNOFF AND RECHARGE VS TIME

LONG TERM WEEKLY MEANS
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER

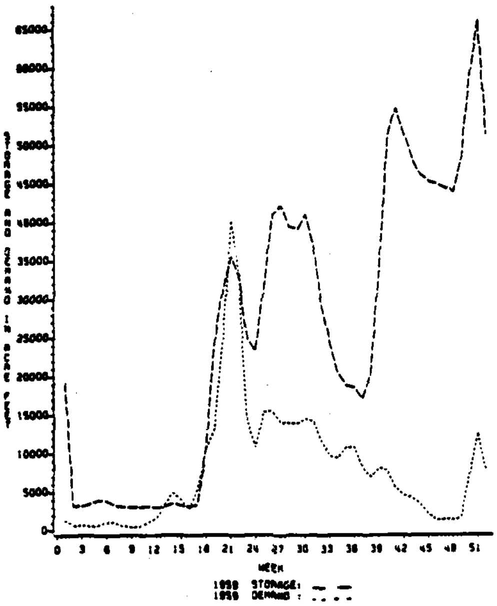



STORAGE, DEMAND VS TIME
1956 DATA ONLY
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER

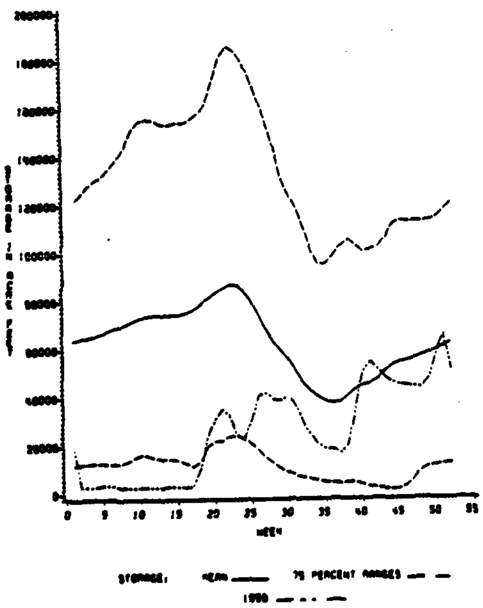

STORAGE VS TIME


DEMAND VS TIME

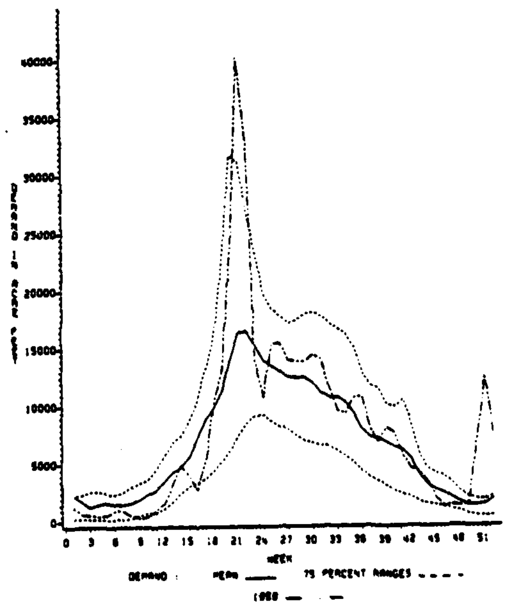
STORAGE, DEMAND VS TIME
1959 DATA ONLY
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER

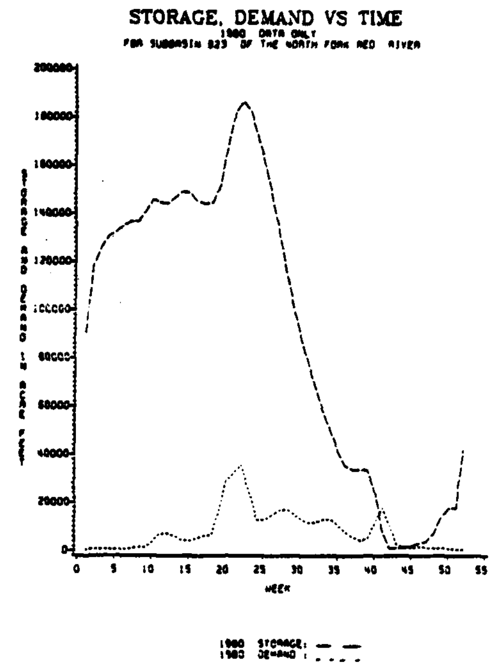


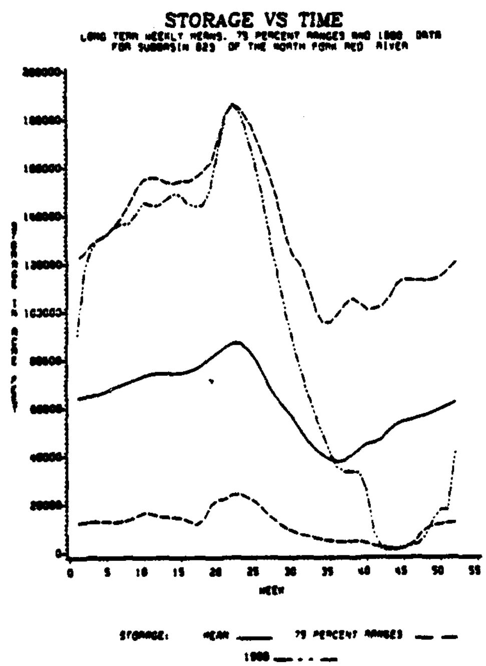
STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1959 DATA
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER

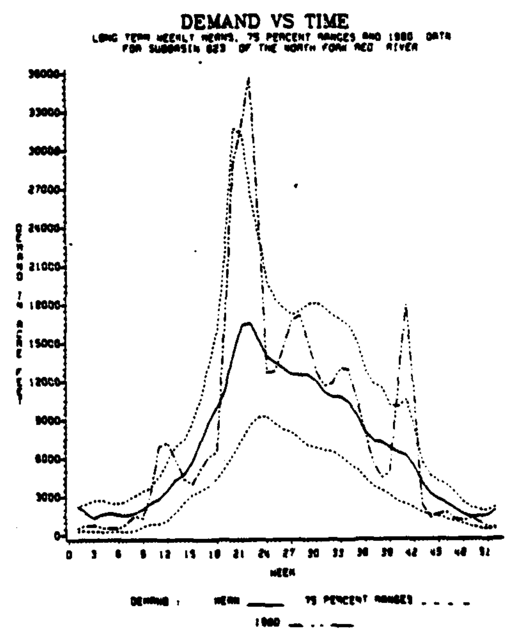


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1959 DATA
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER

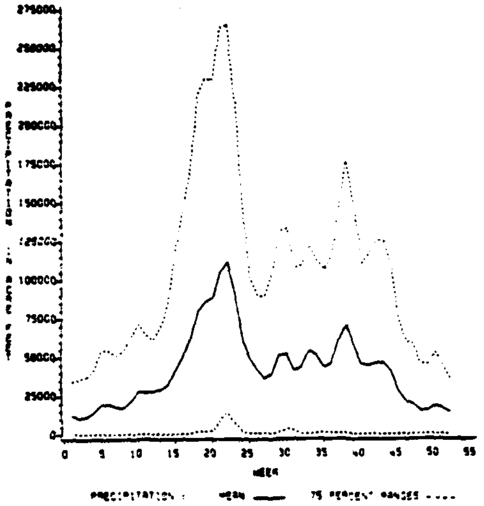



STORAGE, DEMAND VS TIME
1980 DATA ONLY
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER
WEEK
1980 STORAGE:
1980 DEMAND :

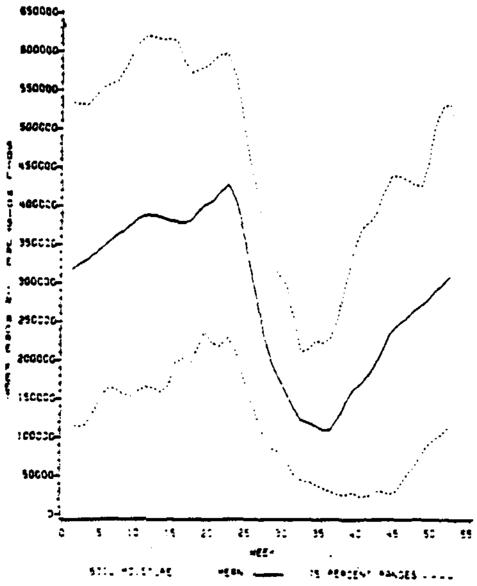

STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1980


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 823 OF THE NORTH FORK RED RIVER
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1980

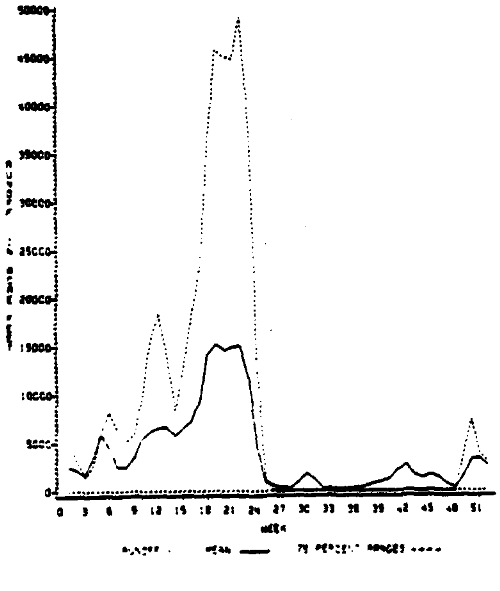
PRECIPITATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER



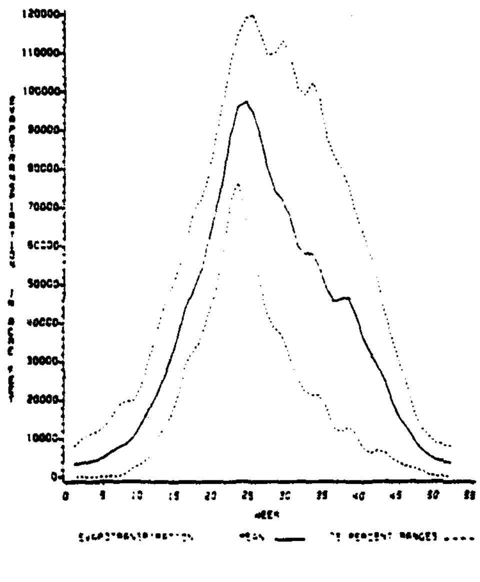
SOIL MOISTURE VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER

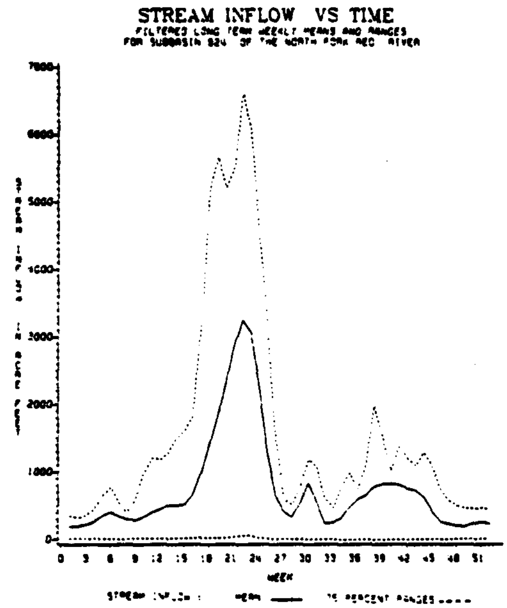


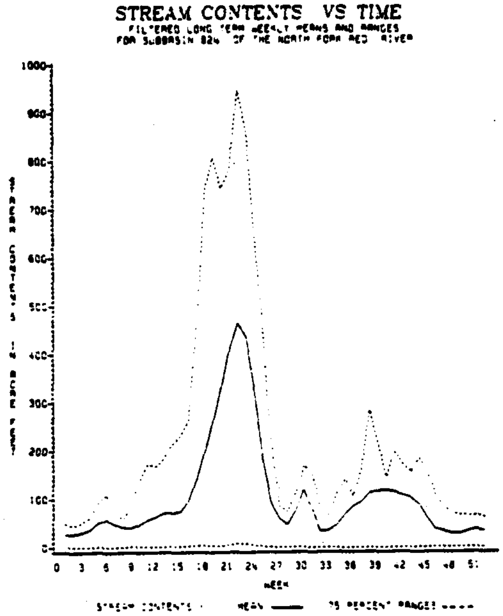
RUNOFF VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER

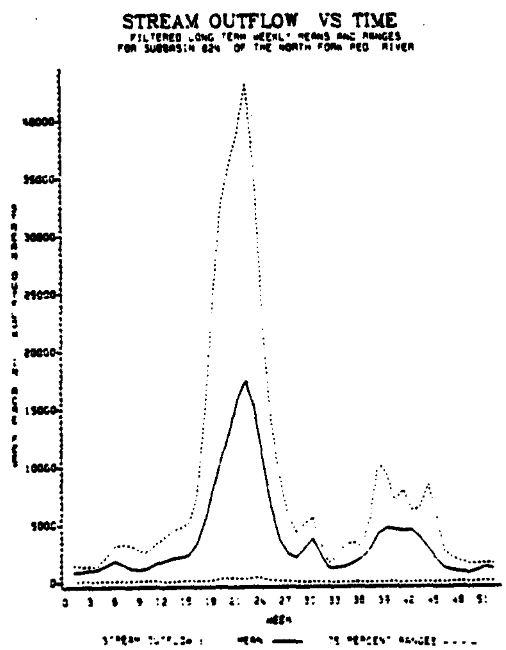


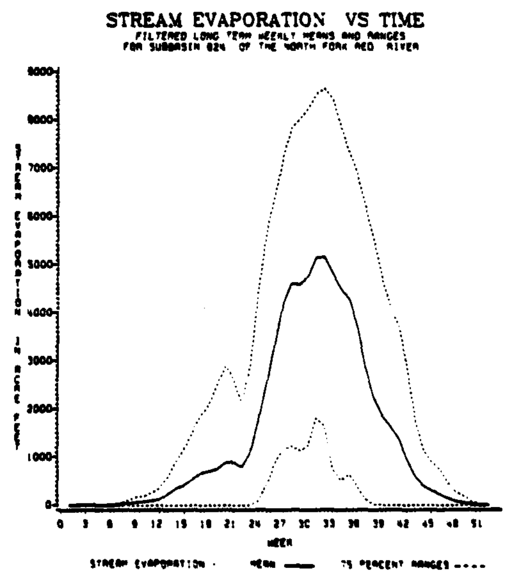
EVAPOTRANSPIRATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER



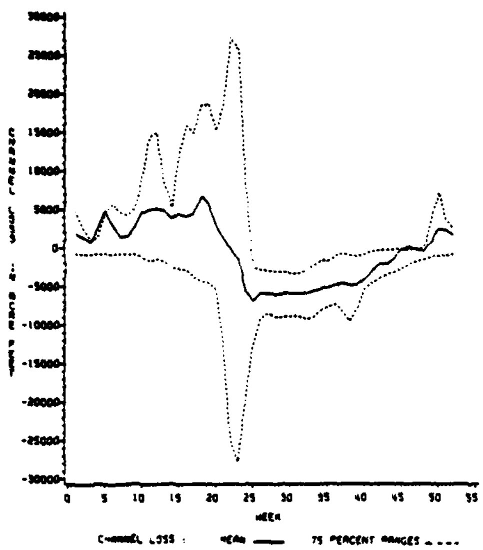

STREAM INFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK


STREAM CONTENTS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK

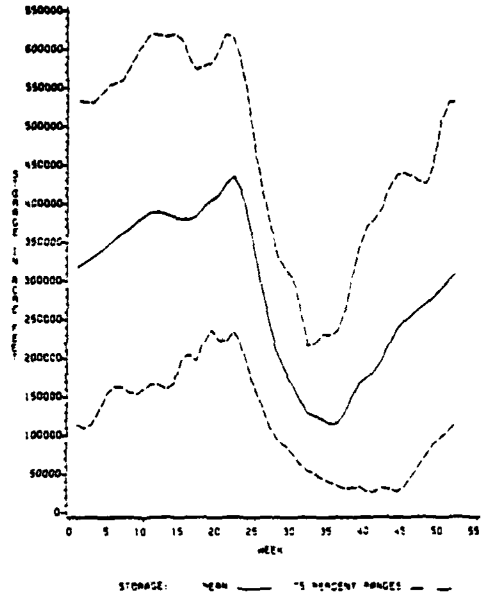

STREAM OUTFLOW VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK


STREAM EVAPORATION VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK
STREAM EVAPORATION : MEAN 75 PERCENT RANGES

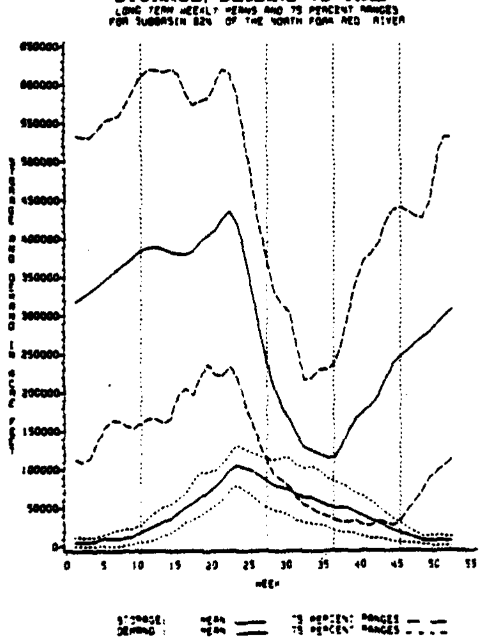
CHANNEL LOSS VS TIME
FILTERED LONG TERM WEEKLY MEANS AND RANGES
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER



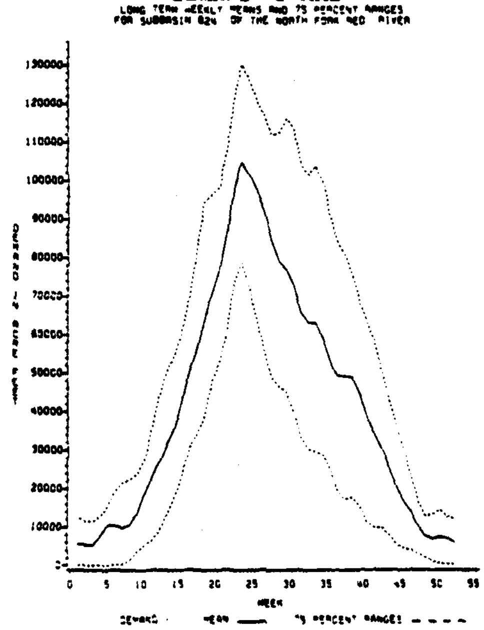
STORAGE VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER



STORAGE, DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER



DEMAND VS TIME
LONG TERM WEEKLY MEANS AND 75 PERCENT RANGES
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER

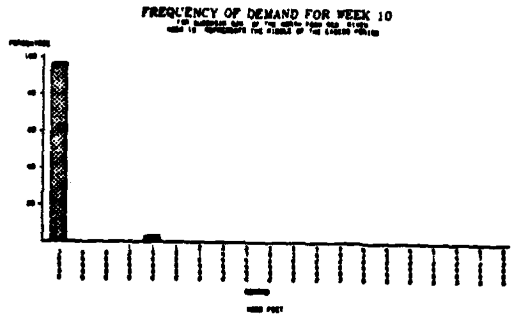


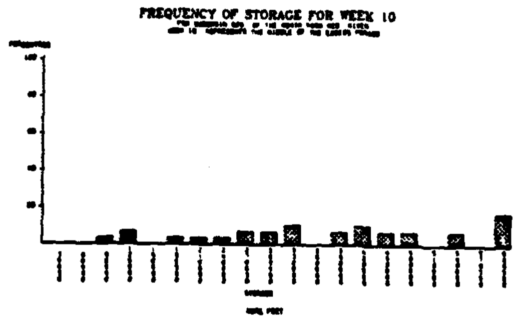
Joint frequency table for subbasin B24, week 10 (mid-excess period).

0	0	0	0	0	1	1	2	
0	0	2	8	7	0	17	15	D
0	0	1	2	7	2	12	160	E
0	0	0	0	0	0	0	380	M
0	0	0	0	0	0	0	610	A
0	0	0	0	0	0	0		N
0	0	3	10	14	3	30		D
2	15	160	380	610				

STORAGE

Storage and demand in thousands of acre feet.



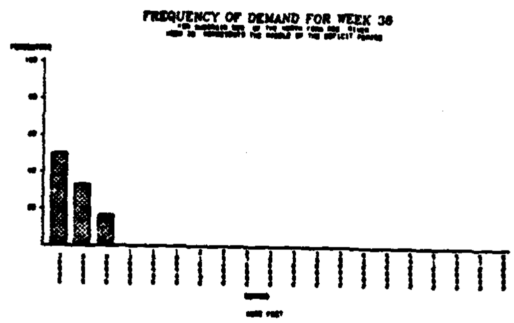


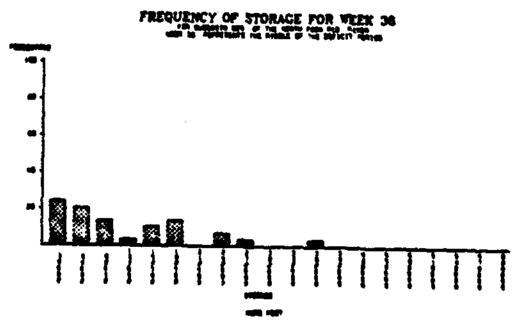
Joint frequency table for subbasin B24, week 36 (mid-deficit period).

0	2	4	0	0	0	6	20	
0	1	7	0	0	0	8	35	D
0	0	1	2	7	4	14	90	E
0	0	1	0	1	0	2	120	M
0	0	0	0	0	0	0	230	A
0	0	0	0	0	0	0		N
0	3	13	2	8	4	30		D
20	35	90	120	235				

STORAGE

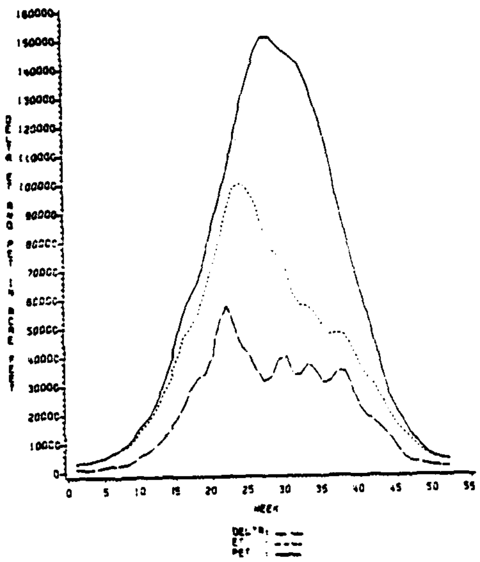
Storage and demand in thousands of acre feet.





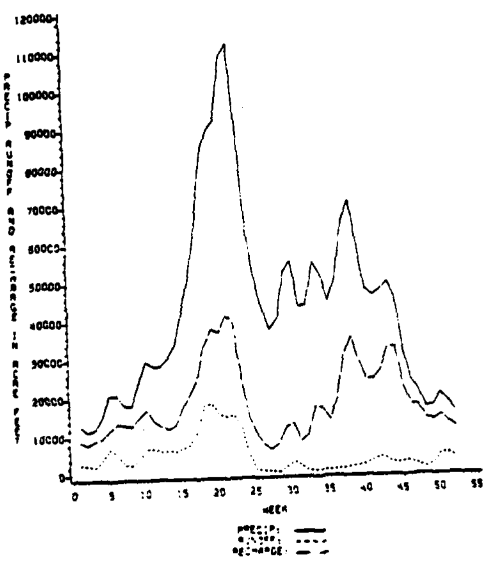
DELTA, ET AND PET VS TIME

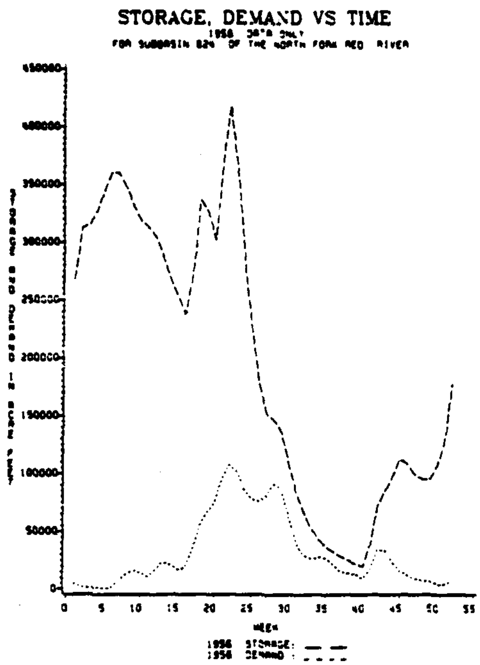
LONG TERM WEEKLY MEANS
FOR SUBBASIN 924 OF THE NORTH FORK RED RIVER

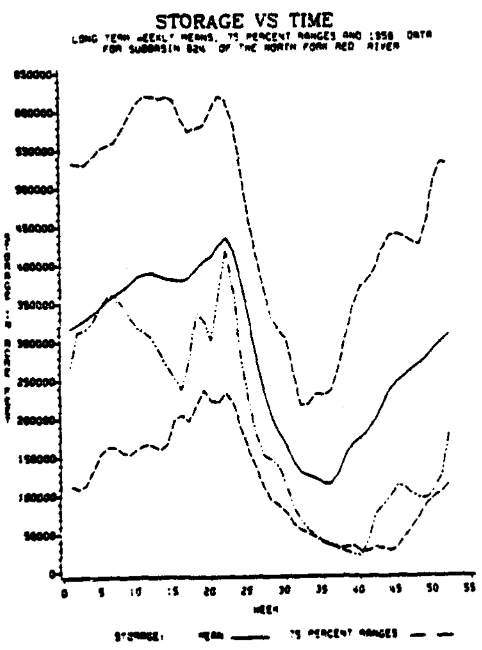


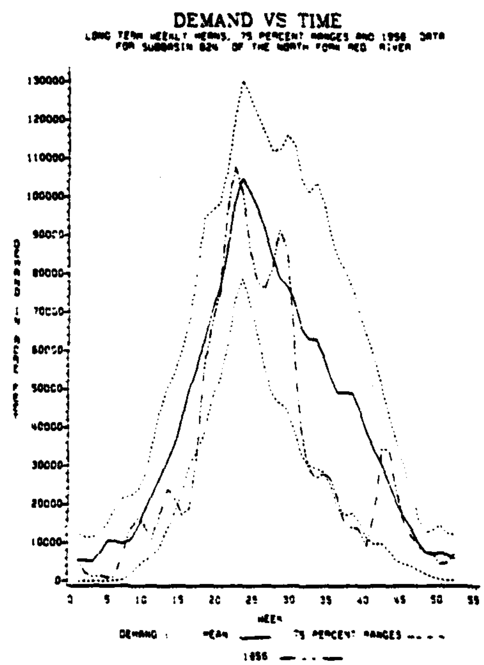
PRECIP, RUNOFF AND RECHARGE VS TIME

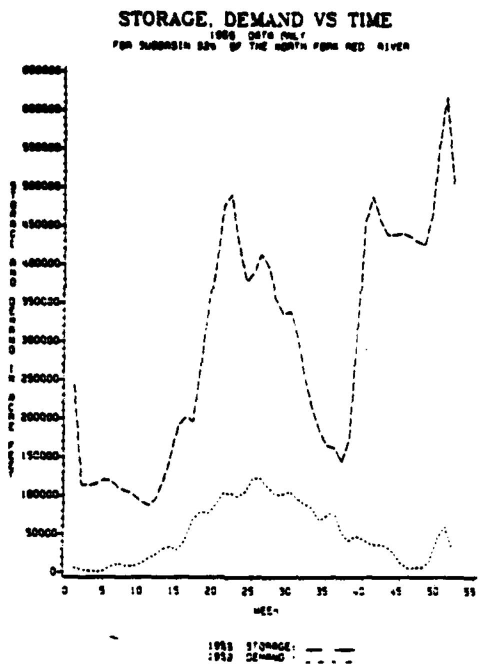
LONG TERM WEEKLY MEANS
FOR SUBBASIN 924 OF THE NORTH FORK RED RIVER

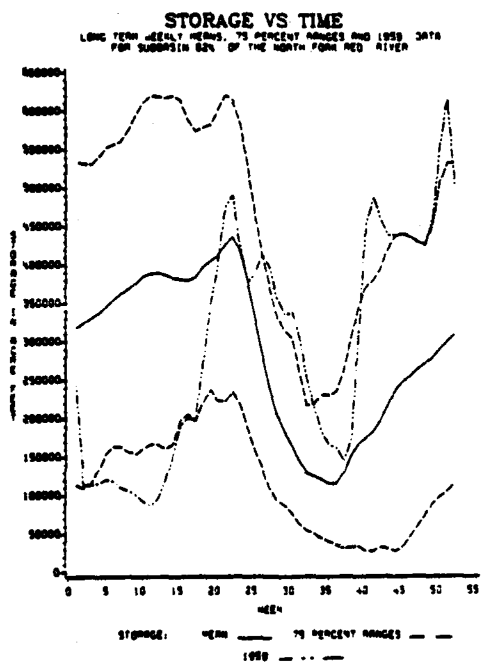


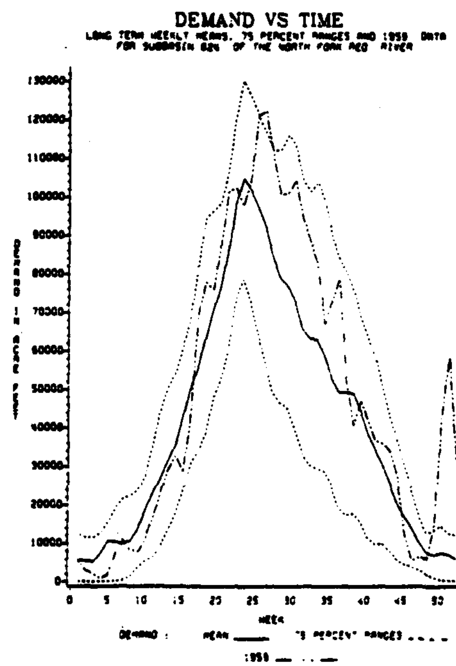

STORAGE, DEMAND VS TIME
1956 DATA ONLY
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK
1956 STORAGE
1956 DEMAND


STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1956 DATA
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1956

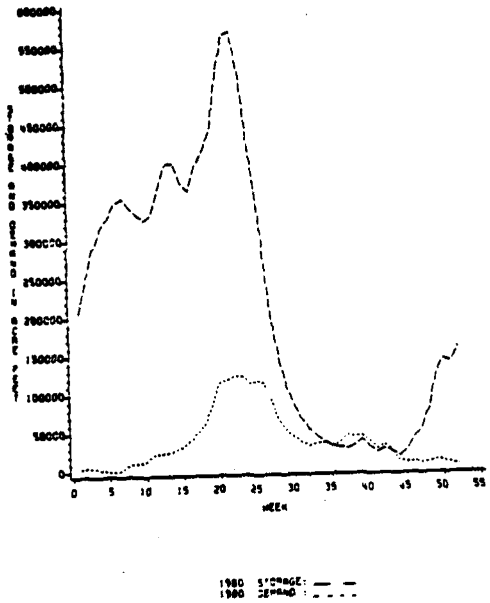

DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1956 DATA
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1956


STORAGE, DEMAND VS TIME
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER
0
50000
100000
150000
200000
250000
300000
400000
0
5
10
15
20
25
30
35
45
50
55

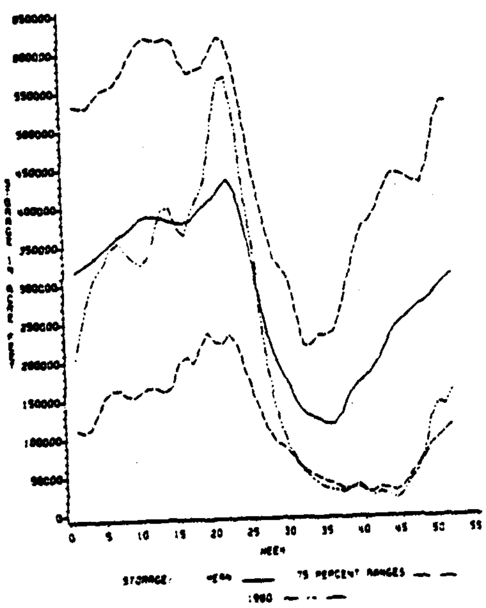

STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1959 DATA
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER
0
50000
100000
150000
200000
250000
300000
350000
400000
450000
0
5
10
15
20
25
30
35
45
50
55
WEEK
STORAGE: MEAN 75 PERCENT RANGES
1959


DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1959 DATA
FOR SUBBASIN 82% OF THE NORTH FORK RED RIVER
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
100000
110000
120000
130000
0
5
10
15
20
25
30
35
40
45
50
55
WEEK
DEMAND : MEAN 75 PERCENT RANGES
1959

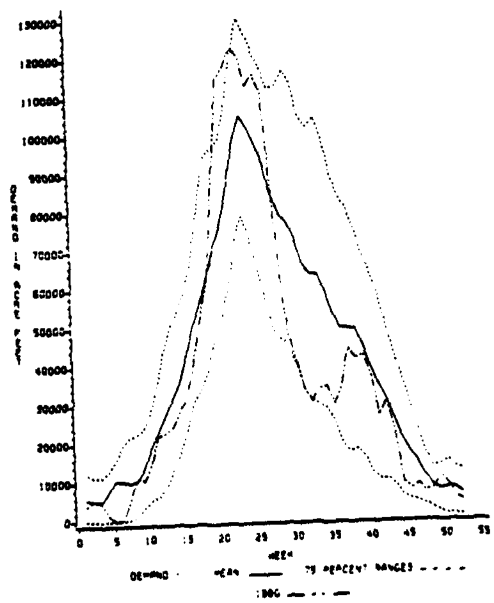
STORAGE, DEMAND VS TIME
1980 DATA ONLY
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER

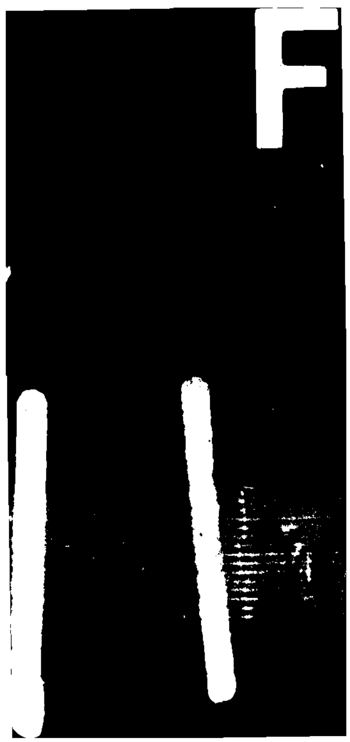


STORAGE VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER



DEMAND VS TIME
LONG TERM WEEKLY MEANS, 75 PERCENT RANGES AND 1980 DATA
FOR SUBBASIN 824 OF THE NORTH FORK RED RIVER

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